Water distribution within smallholder irrigation schemes in Tanzania and its implications for economic inequality

By

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and

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Abstract

This thesis investigates the linkages between water supply and economic inequalities within smallholder irrigation schemes, with particular focus on Tanzania, as a key example of a developing, agrarian economy in sub-Saharan Africa. In developing countries, income inequalities are critical for poverty reduction as they determine how economic growth is distributed and, thus, to which extent the poor benefit relative to everyone else. On a global scale, and in sub-Saharan Africa in particular, poverty is most prevalent in rural areas where agriculture is the main source of livelihoods. Irrigation development is recognised as a key strategy for rural poverty reduction, although a growing body of literature questions its implications for equity and social justice. While this topic is addressed from various perspectives in the literature, there is a gap among empirical studies. Specifically, the linkages between irrigation water supply and economic inequalities at small scales have received limited attention.

To research this need, this thesis carries out quantitative, qualitative and policy investigations on two smallholder irrigation schemes in southern Tanzania. The data originates from structured household surveys, semi-structured interviews with key informants, direct infrastructure observations, maps of the irrigation schemes and documentary sources. The thesis is organised as follows: First, inequality analyses using the Gini coefficient and the Theil index are used to calculate the level and decomposition of income inequalities within six smallholder irrigation schemes in sub-Saharan Africa. Next, qualitative investigations uncover irrigators' perspectives about the association between water supply and economic inequalities within the two Tanzanian schemes. Third, multiple regression analyses evaluate the relative impact of water supply and farm location (as well as other variables) on irrigated crop income and production within smallholder irrigation schemes. Finally, an investigation of Tanzania's water and irrigation institutional framework highlights current policy shortfalls and possible strategies targeting greater equity of irrigation water supply.

This thesis' findings show that high levels of income inequality exist within agricultural communities in Zimbabwe, Tanzania and Mozambique, and that such disparities are not properly considered by development polices based upon national statistics. In particular, within smallholder irrigation schemes, inequities in water supply affect economic inequalities in multiple ways, some of which – for example erosion of human capital and social stratification − are not adequately noted in previous literature. Household characteristics and farm location are also shown to be important for irrigated crop incomes and yields. While typically regarded as a good water management practice, the transfer of responsibilities to the local level is shown in this study to be problematic for traditional irrigators. Instead, in the pursuit of greater equity of water supply, participatory process should be considered based on six key equity aspects: quantity; reliability; obligations; benefits/externalities; decision-making; and land rights.

Overall, this thesis contributes the international development and inequality literature by providing a deeper understanding of: a) the effect of irrigation water supply on economic inequalities; and b) which water policies might be changed to reduce water supply inequities within traditional irrigation systems. These findings are important to respond to rural poverty in Africa, as it is at the local scale that poverty, growth and inequality interventions can be most effective. Importantly, because a large part of the world's rural population seeks pathways out of poverty, it is critical to ensure that income-enhancing strategies, such as irrigation, do not result in aggravated economic disparities and a barrier to sustainable human development.

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I greatly appreciate the advice from my Tanzanian research colleagues Dr Makarius Mdemu, Dr Nuru Mziray and Mr Daniel Isdory. I owe the success of my fieldwork to the three of you; for introducing me to the farming communities and for providing so much knowledge and data about the local context. A special mention goes to my translator, Mussa Malick, whose skills and professionalism allowed me to, almost flawlessly, communicate with interviewees, thus, obtaining some of the most valuable findings of this thesis. My warmest thanks go to all those farmers who shared their knowledge, ideas, concerns and hopes about the irrigation schemes with me. I sincerely wish that, beyond these words, my gratitude will reach you in a more practical form, perhaps by taking another step towards better, more equitable water supply.

To Rosario D'Arpa, my husband and best friend, *grazie* for being the earth beneath my feet. You are a generous, fearless man who never holds back, even when I dragged the whole family into the PhD abyss. To my children and parents, thank you for your admiration and unconditional love. To all my friends, thank you for being there rain or shine.

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List of Acronyms and Abbreviations

ABS	Australian Bureau of Statistics
ACIAR	Australian Centre for International Agricultural Research
AIPs	Agricultural Innovation Platforms
ANU	Australian National University
ASDP	Agricultural Sector Development Program
AUD	Australian Dollars
AWPI	Agricultural Water Poverty Index
BWBs	Basin Water Boards
BWOs	Basin Water Offices
CPRs	Common Pool Resources
CSIRO	Commonwealth Scientific and Industrial Research Organisation
CWCs	Catchment and sub-catchment water committees
DCs	District Councils
DIOs	District Irrigation Offices
DFTs	District Facilitation Teams
FAO	Food and Agriculture Organization of the United Nations
GDP	Gross Domestic Product
GIS	Geographic Information System
ha	hectare
HDI	Human Development Index
IOs	Irrigators' Organisations
IWRM	Integrated Water Resource Management
IWRMD	Integrated Water Resources Management and Development
K-S	Kolmogorov-Smirnov
mm	millimetres
MoWI	Ministry of Water and Irrigation
MZN	Mozambique Metical
NIC	National Irrigation Commission
O&M	Operation and Maintenance
OLS	Ordinary Least Squares
PGI	Poverty-Growth-Inequality
RIOs	Regional Irrigation Offices
RBWB	Rufiji Basin Water Board
RBWO	Rufiji Basin Water Office
sqm	Square meter
SRI	System of Rice Intensification
SSA	Sub-Saharan Africa
SWOT	Strengths, Weaknesses, Opportunities and Threats
TZS	Tanzanian shillings

UN	United Nations
UniSA	University of South Australia
USD	United States Dollar
VIFs	Variance inflation factors
WPI	Water Poverty Index
WRS	Wilcoxon rank-sum
WUAs	Water User Association
Y	Yield
Y_A	Actual Yield
Y_G	Yield Gap
Y_G-to- Y_A	Yield Gap to Actual Yield ratio
Y_P	Potential yield
ZIUs	Zonal Irrigation Units

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Chapter 1 Introduction

1.1 Problem statement

In 2010, the United Nations General Assembly and the Human Rights Council formally recognised water to be a fundamental human right (UN 2010 p. 22). Yet, some 800 million people still remain without adequate access to safe drinking water and many more do not have access to irrigation water. Rather than physical water scarcity, Pérez-Foguet and Giné Garriga (2011) argue that the root of the water crisis is one of management, which needs to be addressed through a multi-disciplinary approach.

Within the context of irrigation, two well-recognised goals are the efficient utilisation and equitable distribution of water resources. A frequent problem in open-channel systems, is the heterogeneity in water distribution, whereby irrigators located closer to the intake tend to withdraw disproportionately more water and more frequently than those located further downstream (Ostrom & Gardner 1993). Such imbalances are particularly acute within traditional, low-technology schemes - common in developing areas - where technical and governance limitations impede adequate control and monitoring of water deliveries. Such disparities in water access play a critical role in determining how the benefits of irrigation may be distributed amongst the members of a society – whether irrigation reinforces pre-existing inequalities or, conversely, it has a positive impact for the poor (Turner et al. 2004). Pointedly, it has been argued that 'inequitable water distribution in large surface irrigation system is one of the major factors contributing to income inequality' (Bhattarai et al. 2002 p. 19).

Income inequality is a major obstacle hindering the potential for poverty reduction at global, regional and country scales. Despite decades of sustained growth in Sub-Saharan Africa (SSA), over half of the population still live in poverty amid some of the world's highest levels of wealth and income inequality (Cogneau et al. 2007). While the drivers of economic inequality are numerous and complex, access to natural resources plays a crucial role in rural areas, where agriculture is typically the main source of livelihoods (Sampath 1988). Irrigation is recognised as an effective strategy for rural welfare and development, yet a growing body of literature raises fundamental questions regarding its implication for equity and social justice (Giordano & de

Fraiture 2014; Gorantiwar & Smout 2005; Van Den Berg & Ruben 2006). As noted by Lipton et al. (2003 p. 414), 'the poor are not an homogenous group' and thus, irrigation may have a different impacts among them. Kanbur (2005 p. 229) points out that, while common analyses focus on the rich-poor gap, poverty reduction polices can 'pit some poor against other poor' as a result of aggravated disparities among them.

Most studies on irrigation water supply and economic inequalities are at a large scale (e.g. regions or countries), and there is a gap in empirical work at the local (micro) scales, partially driven by shortfalls in the data (Ravallion 2001). This PhD research was linked to a broader research project addressing agricultural productivity and livelihood strategies within six smallholder irrigation schemes in SSA (see Section 2.2 for details). The broad questions asked in this PhD research are:

- How large are economic inequalities amongst smallholder irrigators? What drives such disparities? And how do they compare to national statistics?
- Are economic inequalities within smallholder irrigation schemes aggravated by disparities in irrigation water distribution? If so, would better water management mitigate the economic gap?

1.2 Theoretical framework

1.2.1 Poverty-growth-inequality triangle

According to the latest comprehensive data on global poverty, 767 million people (11 percent of the global population) lived in extreme poverty[1] in 2013, down from 1.85 billion (35 percent) in 1990 (The World Bank 2017). Although poverty rates declined across all regions, the progress was uneven and mainly driven by East Asia − notably China and Indonesia − and South Asia− namely India. In SSA, poverty rates dropped from 56 percent in 1990 to 43 percent in 2012, but, because of high population growth, the number of extreme poor remained practically unchanged (UN 2013b). Examining within-country poverty and development, it becomes evident that rural

[1] Extreme poverty is defined as average daily consumption of USD 1.90 (Purchasing Power Parity) or less and means living on the edge of subsistence (The World Bank 2015).

areas are, typically, the most disadvantaged (UN 2014a) and those living exclusively off agriculture tend to be the poorest among the rural populations (Senadza 2011).

The association between poverty, growth and inequality (PGI) is a longstanding area of study in the economic literature, namely since the 1950s. In the aftermath of World War II, rebuilding the international economic systems and stability was a top priority. Thus, fuelling economic growth was a primary focus, both in developed and developing countries. At that time, inequality was largely seen as a secondary concern and efforts to reduce it were regarded as an obstacle for growth (Ravallion 2014). Kuznets (1955) theorised that economic growth and inequality follow an inverted-U shape relationship, whereby short-term inequality may rise with growth, but trickle-down effects will narrow the gap in the long-term. Initial evidence of rising inequalities in developing countries provided support for further theoretical argumentations (Ahluwalia et al. 1979; Robinson 1976) reinforcing Kuznets' hypothesis. Cross-country empirical analyses (Ahluwalia 1976; Srinivasan 1977) also seemed to verify the inverted U-shape growth-inequality pattern. Notwithstanding, such results were undermined by the short time-span of the data available (less than a decade). Hence, the observed associations were mainly driven by growth-inequality differences between countries, rather than within-country changes overtime. Early observations of PGI associations (Adelman & Morris 1973) also raised concerns about the increase in relative and absolute poverty levels; the lack of evidence of trickle-down effects; and the importance of relationships among income-groups as a determinant of income distribution. Ram (1988) argued that the internationally-observed inverted-U relationship was due to structural differences between developed and developing countries and that such pattern was not replicated in sub-samples of developing countries only.

As more data became available in the 1990s, further empirical studies emerged analysing the PGI nexus across countries and over time. Two important determinants of how much the poor benefited from economic development were: a) initial inequality levels; and b) changes in inequality during growth spells (Bourguignon 2004).

Ravallion (1997) found that, at any positive rate of growth, the higher the initial inequality, the lower the rate at which income-poverty falls. Moreover, at very high inequality rates, it is possible for growth to result in rising poverty levels. This contrasts with the affirmation made by

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Dollar and Kraay (2002) claiming that, on average, growth benefits the poor just as much as everyone else, particularly under polices favouring private property rights, macroeconomic stability and openness to trade. Aghion and Williamson (1998 p. 33) argue that macroeconomic volatility and taxation polices play critical roles in the poverty-growth-inequality relationship ant that ‘overall, inequality actually proves *bad* for growth in several circumstances’. Similarly, studies on land asset inequality (Deininger & Olinto 1999; Deininger & Squire 1998) found that initial inequality is negativity associated with long-term growth and that inequality reduces income growth for the poor − but not for the rich. Other mechanisms whereby inequality impacts poverty and growth are: access to credit and education; (un)employment; demand for consumer goods; socio-political instability; investment; and migration. (Alesina 1996).

Using the same data from 60 countries as previously employed by Ahluwalia (1976), Anand and Kanbur (1993) found that the shape of growth-inequality relationship − flat, U or inverted U − very much depended on the statistical methods employed (e.g. logarithmic vs linear regression). Ravallion (2001) examined 117 time spells in developing countries and found that, during growth periods, inequality rises as often as it falls. While poverty is reduced in both cases, the decline rate is seven times greater when inequality diminishes. In an analysis of 130 countries over 25 years, Ferreira and Ravallion (2008) conclude that, globally, there is a clear negative association between levels of inequality and development. Furthermore, the study found no robust evidence that such inequality levels fall with economic growth. Simulation studies by Groll and Lambert (2013), found no evidence that income distribution changes could be inequality-increasing and pro-poor at the same time. The term pro-poor is given several definitions and measurements in the literature (Kakwani & Pernia 2000; Ravallion & Chen 2003; Son 2004), with a common understanding that pro-poor growth is such that it benefits the poor to a greater extent than the rest of the population. Using a dataset sampling 130 countries between 1980 and 2010, Ravallion (2014) reveals that current inequality levels in the developing world are lower than 30 years ago − albeit a steady increase since 2005. The main driver behind such trend is the drop in between-country disparities, whilst within-country inequalities have been slowly rising. This study of new data also ratifies previous findings from the 1990s on the negative impact of inequality on growth and poverty elasticity.

In comparative analyses of PGI across developing regions, Fosu (2009, 2017) found that the responsiveness of poverty to changes in growth and inequality was much lower in SSA than in non-SSA areas (except for Latin America and the Caribbean). In addition to uncovering particularities at regional level, the studies highlight the need for policymakers to look beyond average and take into consideration country-specific drivers of PGI. In Tanzania, between 1983 and 1991, major agricultural reforms brought higher producer prices and greater incomes for some farmers who, then, were able to escape poverty. However, less advanced farmers were left behind, resulting in a 40 percent increase in income inequality. According to Ferreira (1996), if income distribution had not changed during this period, with the same growth level, poverty reduction would have been much greater, i.e. equal to 39 percent, instead of the actual 14 percent. More recently, a study analysing the 2000-2007 growth spell in Tanzania concluded that greater poverty reduction could have been achieved if the absolute increases in real income had been more evenly spread (Atkinson & Lugo 2010). Similarly, between 1995 and 2002 in Mozambique, income levels in rural areas experienced growth as a result of higher food prices. Consequentiality, 60 percent of rural households - who were net grain buyers - were affected by their declining purchasing power and eroded welfare levels (Boughton et al. 2006).

While the literature on PGI is predominantly based at the macroeconomic level, there is a need to understand growth and distributional change at the micro scale (Ravallion 2001). Indeed, averages reflected in national accounts fail to capture heterogeneities across different populations groups – some if which may become worse off during growth spells, even if poverty falls on average. At the micro level, the ability of poor people to benefit from a growing economy may be affected by a number factors, including physical and human capital, location, social exclusion and exposure to risk (*Ibid.*). In SSA in particular, barriers to participation in non-agricultural activities may limit income-earning opportunities for the poor (McCullough 2017). However, inequities within groups of agricultural and non-agricultural households tend to be largest driver of total inequality, rather than disparities between both groups (Cogneau et al. 2007). A recent study in Malawi (Takane & Gono 2017) found that off-farm incomes can be a driver of inequality among agricultural households, yet the level of impact and its direction (inequality increasing or reducing) vary considerable across locations and time. Hence, the authors conclude that context-specific interventions would be more appropriate, rather than policies following a nationwide perception.

The importance of inequality for growth and poverty reduction is formally recognised by the UN as part of its Sustainable Development Goals (UN 2015). Within this framework, goal 10 aims to 'reduce inequality within and among countries' through a set of specific targets. The first target is to achieve income growth of the bottom 40 percent of the population at a higher rate than the national average. Pointedly, the third target is to 'Ensure equal opportunity and reduce inequalities of outcome, including by eliminating discriminatory laws, policies and practices and promoting appropriate legislation, policies and action in this regard'. This is particularly relevant for the scope of this thesis because the key research questions revolve around the impact of water on inequality of irrigation outcomes, and the opportunities for reducing disparities through adequate water management policies.

1.2.2 The importance of irrigation water for poverty, growth and inequality

Linkages between poverty, growth and inequality, commonly observed at macroeconomic level, and also be found at regional and local levels (Jayne et al. 2003; Kabubo-Mariara et al. 2012). As noted by Calderón and Servén (2014), provision public infrastructure typically raises aggregate growth, but can also impact income distribution depending on how different members of the local communities gain access to such services.

In rural areas, especially where people's welfare and potential for growth depend on to their access to water, water management can be one key strategy for addressing multiple dimensions of poverty and pursuing inclusive growth (Peña 2011). Consequentially, the Tanzanian Ministry of Water and Irrigation (The United Republic of Tanzania 2006) highlights the link between water access and inclusive growth by noting that inequitable water allocation and ill-defined water rights pose a major obstacle to poverty reduction.

Typically, farmers relying on rainfed agriculture tend to be poorer than those able to irrigate, mainly due to high seasonal variability of yields and lower market prices of crops on rainfed farming systems (Hussain & Hanjra 2004). Given strong environmental impacts, such as floods and droughts, dryland farmers lacking weather-mitigating strategies, tend to suffer crop and incomes losses, thus potentially pushing them further down into poverty (Silva 2013). In a review of over 120 Asian and African irrigation schemes, Hussain and Hanjra (2003) find strong linkages between irrigation development, agricultural growth and poverty reduction. Arguably, access to adequate irrigation water can alleviate poverty through five key dimensions: crop production, income/consumption, employment, vulnerability/food security, and other social and financial factors. These factors are aligned with the key capitals (natural, physical, human, cultural/social, economic/financial, political and/or built) that form the bases of several community development and resource management frameworks: Sustainable Livelihoods (Scoones 1998), Capitals and Capabilities (Bebbington 1999) and Community Capitals (Emery & Flora 2006; Gutierrez-Montes et al. 2009).

Within the context of irrigation in poor, rural areas, a large body of literature (Hussain & Hanjra 2003; Maskey et al. 1994; Ostrom & Gardner 1993; Senaratna Sellamuttu et al. 2014) identifies significant differences in water access between head and tail-ends within gravity-fed systems. Typically, farms located closer to the system's intake are able to withdraw larger volumes of water with greater reliability compared to those further downstream, thus commonly resulting in underperformance of tail-enders. Disparities in water distribution within low-technology schemes are rooted in a series of complex factors at various levels of management, i.e. national, regional and local. Among others, these may include: ambiguity in the definition of roles and responsibilities of multiple water-governing institutions; limited ability (or willingness) of irrigators to conform to scheme norms (e.g. obeying water-sharing rules and doing maintenance); impeded infrastructure operability due to insufficient level of maintenance and repairs; and lack of objective data to plan and monitor water deliveries.

Drawing from investigations in India and Pakistan, Bhattarai et al. (2002) theorise that inequitable water distribution in surface irrigation systems is one of the major factors contributing to income inequality. Based on observations in India and Mexico, Bardhan and Dayton-Johnson (2007) argue that location advantages and disadvantages between head and tail-end of a canal system can impact long-run wealth disparities through capitalisation into different land values. Similarly, Williams and Carrico (2017) note that, in Sri Lanka, social inequalities are known to relate to locations along the canal, with more powerful farmers often occupying land closest to the water source. Furthermore, Conceição et al. (2016) consider that, in fast-growing sub-Saharan Africa, equitable water distribution is critical to ensure that greater irrigation productivity translates into higher income and food security for the poor. Distribution of irrigation water is, in fact, at the root of social cohesion and stability within traditional systems, as it is a major determinant of collective action (cooperation and conflict) among irrigators (Bardhan 2000; Bardhan & Dayton-Johnson 2007; Dayton-Johnson 2000b; Makombe & Sampath 2003; Ostrom et al. 1999).

1.2.3 Defining equity of water distribution

Despite the increasing recognition of the importance of equity and equality of water distribution, their measurement and definition remain ambiguous. After conducting an extensive review of the concept of water equity, Wegerich (2007 p. 1) argues that 'what remains questionable is, what exactly is equity as regards water management and who defines this and how is it implemented in practice'. Similarly, Kolberg (2012) notes there is still no standard methodology to measure water-related inequality in irrigation water management.

A common consideration in the context of resource allocation is the distinction between 'egalitarianism' and 'proportionality' (Bournaris et al. 2014; Syme et al. 1999). Egalitarianism suggests that everyone should be treated alike and, therefore, resources ought to be distributed equally regardless of individual circumstances. Conversely, proportionality mirrors the concept of 'equity', whereby individuals' needs and demands are taken into account and thus, resources are allocated in a 'just' or 'fair' manner. Typically, irrigation water-sharing rules are based on proportionality of water requirements; hence the use of water equity as the preferred term in the literature, as opposed to water equality. For consistency in this thesis, the term water equity is used when referring to water supply and distribution, unless otherwise specified.

A number of approaches to measure heterogeneities in irrigation water have been proposed, mostly applying methods from wealth economics, e.g. Gini coefficient (Cullis & van Koppen 2007); Theil Index (Anwar & Ul Haq 2013); Atkinson index (Kolberg 2012); coefficient of variation (Lal Kalu et al. 1995; Molden & Gates 1990); and interquartile ratio (Bird 1991; Steiner & Walter 1992). Several authors have attempted to review and synthesise the numerous measures of water equity and equality, with Gorantiwar and Smout (2005) providing one of the most compressive examinations of heterogeneity measurement in irrigation schemes .

Common rules include irrigation time proportional to landholding size (Anwar & Ul Haq 2013) or equality of water depth (Bird 1991; Lal Kalu et al. 1995), which is equivalent to volume proportional to area. Despite aiming for social justice, proportionality can be an imperfect and impractical way to allocate irrigation water resources. For example, water allocation on a time-basis may result in uneven supply due to seepage losses along distributary canals, which reduces available flows at the tail-end (Sharma & Oad 1990). In large-scale, complex schemes, the fairness of water allocation may be difficult to assess because of ineffective communication between operators and many users (Bournaris et al. 2014). Furthermore, proportional distribution necessarily entails higher costs of record-keeping, monitoring and negotiation (Dayton-Johnson 2000a). In a study of land and water rights in Nepal, van Etten et al. (2002) reason that water allocation proportional to land may actually be detrimental to the poor. Although poor households could theoretically sell their water rights, they tend to have small plots that provide only small water allocations. In turn, such small entitlements are too little to generate significant income when sold.

Another common distinction in welfare systems is 'vertical' vs. 'horizontal' equity (Bournaris et al. 2014; Maskey et al. 1994; Wegerich 2007). Vertical equity refers to the distribution of resources amongst individuals with different needs (e.g. different water users or farm categories), whereas horizontal equity is a measure of treatment for those with equal needs (e.g. distribution among smallholder farms).

In many developing countries, such as Tanzania, the most common form of irrigation is traditional, smallholder schemes, water supplies are very rarely quantified, given a widespread lack of adequate technical, financial and human resources (van Koppen et al. 2004). In absence of quantitative, objective data, previous studies have used a variety of proxy measures (see Section 4.2), including irrigators' own perceptions (Starkloff 2001; Tisdell 2003). Building on evidence from rural Mozambique, Ducrot and Bourblanc (2017) note that water supply programs should take into consideration the varying perceptions of water equity among community members. Moreover, the authors propose that equity should be evaluated across three distinct dimensions: distributional equity (spatial coverage), procedural equity (participation) and contextual equity (structural and relational mechanisms). Similarly, Lipton et al. (2003) conclude that there are many complex factors impacting irrigation water distribution and thus, equity should be considered through the lenses of disparities in water quantities, timing, access to inputs, decision-making institutions and negative externalities.

1.3 Research gaps

When investigating the specific linkages between irrigation water supply and economic inequalities, the key points of originality of this thesis that contribute to filling existing literature gaps are: i) the local scale (smallholder communities) and area (sub-Saharan Africa and Tanzania in particular); ii) the combination of the quantitative and qualitative methods in assessing (in)equity of water supply; and iii) the conceptualisation of a new analytical framework for the analysis of equity of irrigation water supply.

Vertical water equity – among users of different kinds - has been the object of several previous studies at the scale of large geographical regions or river basis. For example, the Punjab area in India (Anwar & Ul Haq 2013); the Olifants River Water Management Area in South Africa (Cullis & van Koppen 2007); and the Rufiji River Basin in Tanzania and its Greater Ruaha sub-catchment (Kadigi et al. 2005; Kashaigili et al. 2009; van Koppen et al. 2007). Conversely, horizontal water supply disparities within traditional, smallholder systems remain largely understudied (Saldias et al. 2013). Importantly, Dayton-Johnson (1999) note that resource inequality polices should focus on small-scale systems to maximise the positive impacts of public interventions on rural development. More broadly, Peña (2011) analyses equity from an Integrated Water Resource Management (IWRM) [2] perspective, thus concluding that the causes, dynamics and consequences of water management and social equity should be addressed in the local context, as this is where possible solutions should be grounded. In fact, national or international, overarching institutions only have limited ability to enforce water equity at the local level, as only the systems' insiders can determine whether a situation is equitable or not (Wegerich 2007). Most of the literature at local scales (smallholder schemes) originates from India, Pakistan and Nepal (Anwar & Ul Haq 2013; Bhattarai et al. 2002; Maskey et al. 1994; Mollinga 2003; Ostrom & Benjamin 1993; Sharma et al. 2008). Conversely, fewer studies investigate the impact of irrigation on economic inequality in SSA, for example, Kimmage (1991) in Niger, Makombe and Sampath (1998) in Zimbabwe and Van Den Berg and Ruben

[2] IWRM is defined as a process which promotes the co-ordinated development and management of water, land and related resources, in order to maximise the resultant economic and social welfare in an equitable manner without compromising the sustainability of vital ecosystems (Abdullaev et al. 2009)

(2006) in Ethiopia. Much of the focus in these studies is on the heterogeneities *between* dryland and irrigation farmers, but not disparities *within* irrigation schemes. This thesis focuses on disparities among irrigators in small-irrigation schemes.

The water-economic inequality debate is strongly dominated by the effects of landholding (Bardhan 2000; Dayton-Johnson 2000b; van Etten et al. 2002) and crop yields (Maskey et al. 1994; Ostrom 1993) on agricultural incomes. The common approach in these studies consists of first, quantifying disparities (water, yields land, income, etc.); and second, drawing quantitative associations among the various inequality measures. This method has two major limitations. First, it ignores the fact that in the vast majority of traditional irrigation schemes in developing areas, there is an absolute lack of quantitative measures of water deliveries and that, 'for decades to come' costly flow metering will remain largely absent (van Koppen et al. 2004 p. 13). Therefore, without the input of external expertise and technology, quantifying inequality based on traditional metrics (e.g. volumes and Gini coefficients) remains beyond the capabilities of smallholder irrigators and, thus, has a very narrow applicability at the grassroots levels across the developing world. This thesis addresses such a gap by questioning the water-economic inequality nexus employing a qualitative approach, directly derived from irrigators' personal perspectives (see Chapter 4 for further literature review and research rationale).

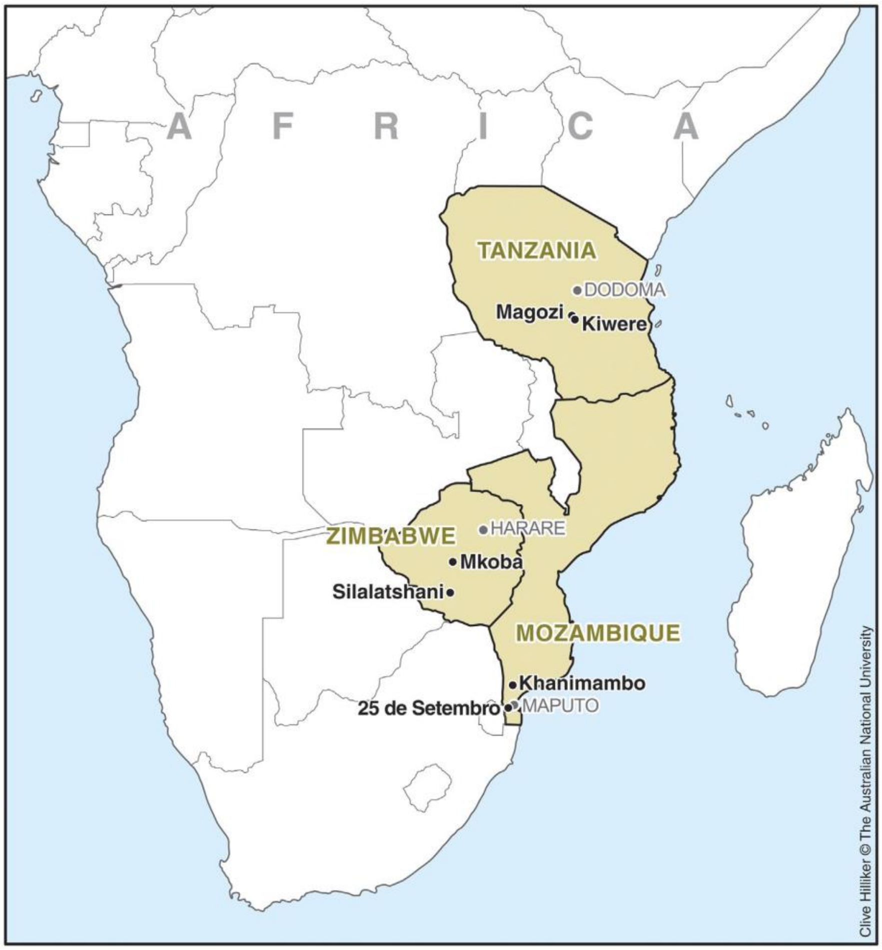
Equity (and equality) of irrigation water supply is a common theme in the agriculture and international development literature, but it lacks a consistent framework of analysis. While Common Pool Resources (CPRs) (Ostrom 1990) and the Water Poverty Index (WPI) (Sullivan 2002) are well-recognised frameworks across the literature (see Chapter 6 for details), there is no such equivalent in terms of the equity of irrigation water supply. Thus, based on a thorough review of past studies and insights from the author's own fieldwork, this PhD conceptualises a framework that allows for the analysis of six key factors in terms of the equity of irrigation water supply. In a practical application, this PhD evaluates Tanzania's current water and irrigation polices to highlight shortfalls and then, based in the research finding, highlight possible policy options.

1.4 Project background

This thesis was affiliated to a larger research project entitled ‘Increasing irrigation water productivity in Mozambique, Tanzania and Zimbabwe through on-farm monitoring, adaptive management and agricultural innovation platforms’ (ACIAR 2013). The project encompasses a number of African and Australian research initiations, including the Australian National University (ANU) and the University of South Australia (UniSA). Hence, this thesis has been developed under the Memorandum of Understating between ANU and UniSA that allows for the delivery of joint PhD degrees in fields where both institutions have common strategic goals.

The project was funded by the Australian Centre for International Agricultural Research (ACIAR) and focused on six smallholder irrigation schemes: Mkoba and Silalatshani in Zimbabwe; Kiwere and Magozi in Tanzania; and 25 de Setembro and Khanimambo in Mozambique (Figure 1-1).

Figure 1-1 **Locations of the six irrigation schemes.**



Source: Mwamakamba et al. (2017)

The broad aim of the ACIAR study was to investigate ways to increase agricultural water productivity and food security through the development of Agricultural Innovation Platforms (AIPs) – a communication system between multiple agricultural stakeholders. Through participatory processes across the six irrigation schemes, van Rooyen et al. (2017) identified 32 major challenges. The most common topic was water, with 11 issues referring to water availability, reliability, governance, fees or supply infrastructure. Other key problems referred to farm inputs (9), human capacity (7) and markets (5).

Out of the three countries, this PhD focuses on Tanzania for because of the interest of the country's recent water policy reforms and the suitability of the two schemes (Kiwere and Magozi) for the specific purpose of researching water and economic disparities. Preliminary observations in the Tanzanian schemes (Mdemu & Mziray 2014) found remarkable socio-economic differences among the irrigation schemes (Figure 1-2). For example, focus groups discussion in Kiwere pointed out that only a few families (around five percent of the irrigation community) were perceived as being ‘rich’, as they owned brick houses, big farms, farming machinery and/or their own business. By contrast, it was understood that over half of the community members were ‘poor’, i.e. food insecure, landless, living in mud-built home and/or unable to send their children to school.

Figure 1-2 **High and low quality houses in Kiwere, Tanzania**

Source: Mdemu and Mziray (2014)

During field observations and discussions with irrigators, inequities in water supply across the scheme were noted. Some irrigators in Magozi commented that uncertainty of supply made it very difficult for them to adequately plan their farming activities. Moreover, it was pointed out that, while some areas (typically head-end of the scheme) have better water provision (volumes and timing), all irrigators pay the same fees – proportional to irrigated area, but irrespective of adequacy of supply.

Figure 1-3 **Rice fields in Magozi: flooded (left), adequately irrigated (centre) and water-scarce (right)**

Source: Authors' fieldwork in 2015

Chapters 2 and 3 provide further information on the ACIAR project goals, the rationale for area selection, and the economic and agricultural situation in each country. Chapters 4, 5 and 6 provide detailed background information on water and irrigation in Tanzania.

1.5 Research objectives

The main research objective of this thesis is to understand how inequities in irrigation water supply are associated with economic inequalities within smallholder irrigation schemes. To answer this broad question, the analysis is subdivided into four distinct parts, whose main objectives are to:

1. Estimate the level of economic inequality within six SSA smallholder irrigation schemes and its decomposition by types of economic activity.
2. Identify the key linkages perceived by smallholder irrigators between water supply and economic inequalities.
3. Evaluate the relative impact of water supply (holding all other influences constant) on irrigated crop income and production within smallholder irrigation schemes.
4. Understand the shortfalls of Tanzania's water and irrigation polices in terms of equity of supply and propose policy options to be considered by local actors.

Water supply and economic inequalities can be defined in multiple different ways (see Sections 1.2.3 and 3.5). Chapter 3 focuses on household income inequality and its decomposition. In Chapter 4, the definition of economic inequalities from water remains purposely broad with the aim to stimulate interviewees' answers from their own personal and unrestricted viewpoint. In Chapter 4, the focus is on water supply inequality, while in Chapter 5, 'adequacy of water supply' is used as a proxy for actual water supply. Farm locations within the irrigation schemes are also used to investigate differences in water supply. In the absence of flow metering or other systematic records within the irrigation schemes, this thesis focuses strongly on irrigators' perception as a way to evaluate water supply. Thus, a mixed-method approach – combining quantitative and qualitative methods – is used to better understand causes, consequences and possible changes related to equity of irrigation water supply.

A primary assumption made in this thesis is that smallholder irrigation schemes in Tanzania, like in many other agricultural areas of the developing world, have a significant potential to improve the management of water resources, including reducing water supply inequities. Furthermore, the assumption made is that water distribution improvements may contribute to mitigating economic inequalities, given the recognised association between water access and welfare. The second key underlying assumption is that the connection between water and economic inequalities is complex and many possible linking mechanisms exist beyond the well-known studied impacts of farm incomes and yields. Third, it is assumed that, irrigators themselves play a critical role in defining, monitoring and enforcing equitable water supply at the local level, although adequate regional and national policies are may be important for successful governance of smallholder irrigation schemes.

1.6 Thesis structure: contents, key results and limitations

This thesis examines the linkages between water supply and economic inequalities from different perspectives following the four key research objectives. The structure consists of four analytical chapters, as well as Introduction, Background and data, and Conclusions. Each analytical chapter is an independent essay, yet the questions of analysis and the results are articulated in a cohesive manner, thus contributing to the overarching goal of the thesis. A summary of the objectives and rationale for research of each chapter is presented in Table 1-1.

Table 1-1 **Thesis structure and theoretical framework for different chapters**

Chapter	**Research questions**	**Rationale for research**
1	What are the objectives of this thesis?	
2	What are the background and data used in this thesis?	
3	What are the levels of economic inequality within smallholder irrigation schemes and how do they compare to national averages? How do different economic activities contribute to total inequality?	Using the PGI framework in developing countries (Fosu 2009); Fosu (2017), and building on the literature calling for i) micro-empirical work on PGI (Ravallion 2001) and ii) context-specific analysis of the drivers of income inequality (Takane & Gono 2017) , Chapter 2: • Estimates income inequality (Gini coefficient) within six smallholder irrigation schemes in SSA and compares it to national statistics; • Decomposes income inequality by economic activity sector (between/within group Theil index decomposition); and • Decomposes income inequality by source (Gini decomposition) and carries out marginal effects analysis.
4	What are irrigators' perceptions on water equity within their schemes? Is there a perceived linkage between water (in)equity and economic inequality?	Departing from the framework for the analysis of irrigation water management in heterogeneous irrigation schemes (Giordano & de Fraiture 2014; Gorantiwar & Smout 2005; Van Den Berg & Ruben 2006), and responding to the need to consider irrigators' perceptions on water equity (Tisdell 2003), Chapter 3: • Explores possible linking mechanisms between water equity and economic inequalities within two smallholder irrigation schemes; and • Evaluates differences in various measures of crop production across population sub-groups determined by their level of water supply satisfaction
5	What is the effect of irrigation water on crop yields and irrigated crop incomes, while holding other variables constant?	Using frameworks of community development and resource management (Bebbington 1999; Emery & Flora 2006; Gutierrez-Montes et al. 2009; Scoones 1998) and based on the hypothesis that heterogeneities in water supply between head and tail-enders cause of differences in crop production and irrigated crop income (Hussain 2005; Ostrom 1993), this chapter: • Evaluates the relative impact of human, social, financial, natural, physical, and farm management factors on irrigated crop incomes and yields. • Identifies those influences that are most susceptible to change and that could provide the greatest benefits for the community. • Tests the relative impact of farm location (and other water variables) on yields and incomes, whilst holding all other variables constant
6	What are the multiple dimensions s of water equity within the specific context of irrigation? How do water and irrigation polices in Tanzania address the goal of water equity at the local level?	Over the last decades, Tanzania – as many other SSA countries - has decentralised authority to manage water and irrigation, from the national to the regional and local levels (van Koppen et al. 2004). Although Irrigators Organisations have the responsibility to ensure equity of irrigation water supply, this goal remains unfulfilled in Kiwere and Magozi, as two examples of Tanzanian smallholder schemes (Mwamakamba et al. 2017). The causes are complex and varied (technical, social, institutional, etc.) and thus, need to be better understood to be able to discuss relevant policy options.
7	What are the key conclusions of this thesis?	

Chapter 2 provides an explanation of the data used in this thesis, including a description of the information used, its sources and the collection methods. This thesis is linked to a larger research project entitled ‘Increasing irrigation water productivity in Mozambique, Tanzania and Zimbabwe through on-farm monitoring, adaptive management and agricultural innovation platforms’, funded through the Australian Centre for International Agricultural Research (ACIAR 2013). Through this overarching project, the first set of data were obtained, consisting of quantitative answers to a household survey conducted in 2014 across six smallholder irrigation schemes. The second source of data is the author’s fieldwork carried out in the Kiwere and Magozi schemes in Tanzania, between May and August 2015. The information collected by the author includes quantitative and qualitative data from the schemes, as well as policy documentation at the local and regional scales.

Chapter 3 provides an insight into income inequalities at the level of smallholder irrigation schemes in SSA. The motivation for this research is that, although economic inequalities are understood to hinder the potential for poverty reduction, there is very little understating of inequalities at the small-scale, mainly due to lack of data. Thus, Chapter 3 first estimates the levels of income inequality (Gini coefficient) within six smallholder irrigation schemes and compares them to national statistics. Second, a statistical analysis and Theil Index decomposition evaluate the differences *between* and *within* household groups defined by economic activity (agricultural or diversified). Third, a Gini decomposition and marginal effect analysis by four income sources identify which are the sources that most contribute to total inequality and which have an equalising/unequalising effect. To summarise, Chapter 3 highlights the importance of understating income inequalities at small scales, which may actually exceed and be overlooked by aggregate national statistics. Furthermore, Chapter 3 argues that policies targeting economic inequalities within smallholder agricultural communities should not be generalised. Based on the six schemes of study, possible interventions could consider income diversification as well as increase of income from sources having an equalising effect, such as agriculture.

Chapter 4 investigates the linkages between economic inequality and heterogeneities in irrigation water supply in the Tanzanian Kiwere and Magozi schemes. The contribution of this chapter lies in the use of qualitative methods, such as open-ended questions, to provide irrigators with the opportunity to freely express their opinions and perceptions. The results first identify the main reasons that, according to interviewees, cause inequity of water supply within their schemes, i.e. water scarcity, weak governance and poor understanding of rules. Second, Chapter 4 unveils a number of complex mechanisms whereby irrigators believe a more equitable water supply could help mitigate economic inequalities. Interestingly, these qualitative investigations reveal new linkages, such as social stratification and erosion of human capital. Third, statistical analyses evaluate whether the linkages identified through subjective interpretations are, in fact, reflected in various quantitative measures of crop production. The results suggest that irrigators who are dissatisfied with their water supply underperform in several ways (yields, land failure and financial losses), yet the yield gap analysis tends to indicate that they hold the greatest growth potential if their water supply was improved.

In Chapter 5, two multiple regression models (based on the Tanzanian schemes) are built to test the hypotheses that adequacy of water supply (and proximity to the system's intake) are positively associated with irrigation incomes and crop yields. Drawing from the literature and fieldwork, a list of independent variables are included in the general (theoretical) models. Chapter 5 concludes by discussing if, and why, the hypotheses are confirmed by the models and what other key factors should be considered by water and irrigation management policies. While 'water satisfaction' is shown to be statistically significant for only yields, physical location appears to be influential for yields and income.

Chapter 6 analyses Tanzania's water and irrigation institutional setting and its policies in matters of equity of water supply. Upon review of existing literature and findings from the fieldwork, a framework is provided to analyse the equity of irrigation water supply. This framework is used to highlight the current policy shortfalls in Tanzania and facilitate the discussion of possible options aimed at greater equity of irrigation water supply. Chapter 6 concludes that the overlap and ambiguity in the responsibilities among various national, regional and local institutions is one of the key areas that deserve further attention. A key finding is that, while Irrigators Organisations (IOs) are relatively young governance bodies, they hold a great potential to develop in ways that support more equitable water supply – a highly desirable goal by most irrigators.

Chapter 2 Data sources, descriptions and limitations

2.1 Introduction

This chapter describes the data used in this thesis, provides details on the collection processes, the information obtained and also limitations. The two main sources of data are: 1) the 2014 baseline survey carried out by local researchers in Zimbabwe, Tanzania and Mozambique and 2) the 2015 fieldwork carried out by the author in Tanzania.

2.2 Research framework: ACIAR project

This PhD thesis is affiliated to a larger research project entitled ‘Increasing irrigation water productivity in Mozambique, Tanzania and Zimbabwe through on-farm monitoring, adaptive management and agricultural innovation platforms’ (ACIAR 2013). The project was funded with AUD 3.3 million from the Australian Centre for International Agricultural Research (ACIAR) over four years, from June 2013 to June 2017. The author received very significant support from the ACIAR Africa project including finance, guidance, logistical assistance and access to data. A second stage of the project was approved in July 2017.

The broad aim of the ACIAR Africa project was to investigate ways to increase agricultural water productivity and food security through the development of Agricultural Innovation Platforms (AIPs). The AIP is a relatively new participatory communication system between farmers and their multiple stakeholders along the agricultural value chain. The specific objectives of the ACIAR project were to:

1. Develop, test and deploy innovative water and solute monitoring systems to stimulate farmer learning toward greater water productivity.
2. Evaluate whether agricultural innovation platforms, based on existing community organisations can identify and overcome institutional and market barriers to greater water productivity.
3. Identify and communicate economic and policy incentive mechanisms for greater water productivity.

Research carried out as part of the ACIAR Africa project research has led to the following publications: Bjornlund and Pittock (2017); Bjornlund et al. (2017a); de Sousa et al. (2017); Manero (2017); Mdemu et al. (2017); Moyo et al. (2017); Mwamakamba et al. (2017); Pittock et al. (2017); Stirzaker et al. (2017); van Rooyen et al. (2017); Wheeler et al. (2017).

2.2.1 Selection of study areas

The countries of study in the ACIAR project were selected following a scoping exercise across Southern and Eastern Africa. The review was conducted by the ANU and Commonwealth Scientific and Industrial Research Organisation (CSIRO) based in Australia, together with a series African research and government organisations (Pittock et al. 2013). Initially, nine African nations were considered where Australia has longstanding engagements (Botswana, Ethiopia, Kenya, Malawi, Mozambique, Tanzania, Uganda, Zambia and Zimbabwe). The candidate countries were evaluated based on their existing ties with Australia, their potential to increase food production, favourable policies and institutions, stable governance structures and regional research networks (Rhodes et al. 2014). Zimbabwe, Tanzania and Mozambique were prioritised for the potential to tackle poverty and food insecurity through stronger growth in irrigated agricultural production.

2.2.2 The six irrigation schemes

Following the scoping exercise, two irrigation schemes were chosen in each of the three countries of study (Table 2-1). The scheme section was made by local research partner organisations based on their institutional capacity, ability to improve agricultural practices, accessibility and the interest of local agencies in collaboration. Further detail on the economic and agricultural characteristics of the irrigation schemes is provided in Chapter 3.

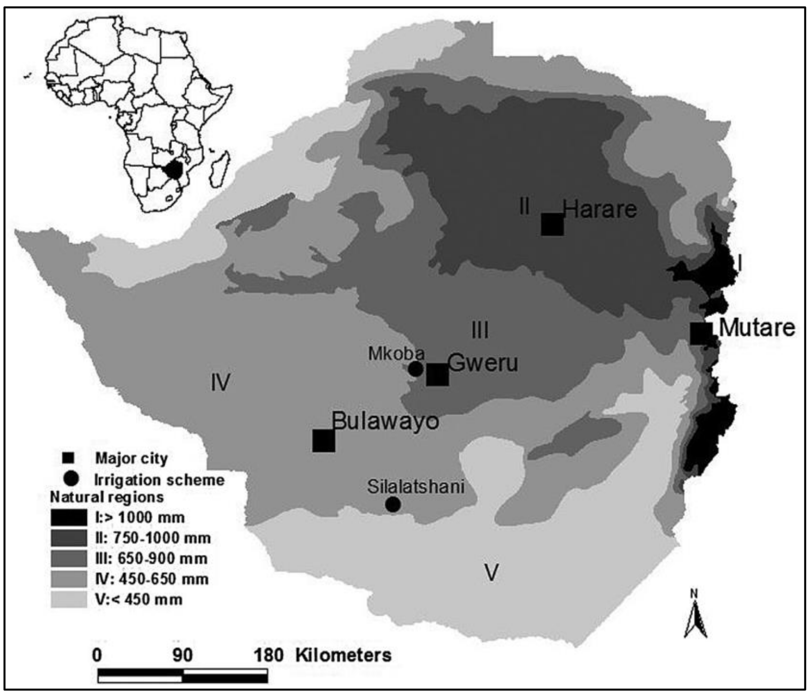
Table 2-1 **Characteristics of the irrigation schemes and surveys undertaken**

Country	District and Area	Irrigation scheme	Main crops
Zimbabwe	Gweru Rural - Natural Region V	Mkoba	Maize, vegetables
	Insiza – Natural Region IV	Silalatshani	Maize, wheat, vegetables
Tanzania	Iringa - Southern Highlands	Kiwere	Vegetables, maize
	Iringa - Southern Highlands	Magozi	Rice
Mozambique	Boane – Maputo Province	25 de Setembro	Vegetables
	Magude –Maputo Province	Khanimambo	Vegetables

Source: Rhodes et al. (2014)

The Mkoba and Silalatshani schemes, in Zimbabwe, are located in a semi-arid region in the southern part of the country (Figure 2-1). Arid and semi-arid areas of Zimbabwe account for 80 percent of the total area and are characterised by erratic rainfall. Within these areas, irrigation provides an important opportunity to increase agricultural production, compared to dryland (FAO 2016). Ninety percent of the area irrigated by settlers and smallholders is under surface irrigation, with water being drawn from rivers, storage reservoirs or deep boreholes (Coche 1998). This is consistent with the Mkoba and Silalatshani schemes, which are fed from storage dams and irrigate using surface methods.

Figure 2-1 **Map of irrigation schemes in Zimbabwe**



Source: Moyo et al. (2017)

The two Tanzanian schemes, Kiwere and Magozi, are located in the Southern Highlands area, within the Iringa region (Figure 2-2). Farming is the main economic activity in Iringa, employing almost 80 percent of its population and making it one of the five largest food-producing regions of the country (Swai 2005). The Kiwere and Magozi schemes are supplied from the Little Ruaha River. Water is then distributed through a network of open channels, some of which are concrete or stone lined. This type of schemes is very common in mainland Tanzania, where almost all irrigation water comes from surface sources and smallholder systems typically consist of lined and unlined gravity-fed canals (FAO 2016).

Figure 2-2 **Map of irrigation schemes in Tanzania**

Source: Mdemu et al. (2017)

The 25 de Setembro and Khanimambo schemes in Mozambique schemes are located within the Maputo province. The Southern region − which Maputo province belongs to − is one of the country's most important agricultural areas and holds two-thirds of all the land equipped for irrigation (FAO 2016). This area has a semi-arid climate and receives most of its rainfall concentrated over hurricane and cyclone events during the wet season (McSweeney et al. 2010). Given the unreliability of rainfall for dryland farming, irrigation development through small, communal schemes is one the key strategies to increase agricultural productivity and food security (República de Moçambique 2010). A national survey on irrigated agriculture (Marques 2006) identified that 62 percent of all irrigation schemes in Mozambique were under 50 ha. These small schemes are mostly operated by farmers individually or organised in an association (FAO 2016). As in the 25 de Setembro and Khanimambo schemes, in Mozambique's traditional irrigation schemes, water is typically abstracted from surface sources by diesel pumps manged by the irrigators and distributed across the fields through gravity-fed methods. These differ from both the Zimbabwean and Tanzanian schemes as running the pumps imposes significant extraction costs on irrigators.

Figure 2-3 **Map of irrigation schemes in Mozambique**

Source: República de Moçambique (2014)

2.3 Baseline survey 2014

The baseline survey for the overall ACIAR study was conducted between May and July 2014 in each of the six irrigation schemes. The areas under irrigation were subdivided into plots, each of which is cultivated by one family, with some families cultivating more than one farm plot. Given the association between farm plot and household − not farm and individual − the data collection process was designed using households as the basic unit.

The populations of study were defined according to the Irrigators' Organisations (IOs) member registry. This means that irrigators who are not registered members of their respective IOs were excluded from the study. Studying the entire irrigation communities was not possible because there is no comprehensive list of all irrigators, thus impeding adequate probability sampling. Conversely, IOs keep up-to-date lists of all their members, which served as the basis of the sampling. Sampling methods varied depending on the size of the population of each irrigation scheme. In the three smallest schemes − Mkoba (Zimbabwe), 25 de Setembro and Khanimambo (Mozambique) − the aim was to interview the whole population, yet some irrigators asked to be excused and others were absent. In the three largest schemes - Silalatshani (Zimbabwe), Kiwere and Magozi (Tanzania) - the population was sampled using a stratified approach. Households were categorised according to gender of the household head and wealth category (poor, medium and well-resourced) and then randomly sampled (Moyo et al. 2014). A summary of the population and samples is provided in Table 2-2.

The 2014 survey consisted of 65 structured questions relative to the 12-month period prior to the interviews, regarding the family structure, farm characteristics, agricultural practices, revenues and expenses, among other topics. Most of the questions of the baseline survey followed a close-ended format, including numerical values (e.g. age, incomes), multiple choice (e.g. crops grown, assets owned) and Likert scales (e.g. agreement with a certain statement). A copy of the baseline survey questionnaire is provided in Appendix A. Each participating household was identified with a unique respondent code that would be used to match its records to further information collected during subsequent surveys.

The 2014 surveys were conducted by trained enumerators and the data recorded in paper-copies of the questionnaires. Upon completion of the surveys, each country team coded their data into a SPSS database. Subsequently, for this thesis, the country data was imported by the author from SPSS into Stata 13®, which was used to conduct the data review and clean-up process. Data from the six schemes was combined into one dataset, which facilitated cross-scheme and cross-country analyses. Many observations were identified with unusual values regarding family characteristics, farm sizes, incomes and expenses, among other variables. These could potentially be due to errors during the data collection and/or coding processes. Hence, a list of observations was sent to be verified by the respective in-country teams. In most cases, the local researchers were able to correct erroneous entries (e.g. wrong decimal points, typos, blanks coded as zeros, etc.). In some other cases, the unusual values remained and were dealt with at later stages this thesis (see chapters 3 and 5).

Table 2-2 **Population and sample characteristics of the six irrigation schemes from the 2014 baseline survey**

	Zimbabwe		Tanzania		Mozambique	
	Mkoba	Silalatshani	Kiwere	Magozi	25 de Setembro	Khanimambo
Total area (ha)	10	110	189	939	38	16
Number of registered households	75	212	199	578	38	27
Surveyed households in 2014	68	100	100	100	25	9
Average household landholding (ha)	0.13	0.52	0.95	1.62	1.00	0.59

2.4 Tanzania fieldwork in 2015

The author’s PhD fieldwork was carried out in Tanzania between May and August 2015. Due to funding and time constraints, investigations were limited to one of the three countries of the overarching project. After evaluating various options, Tanzania was selected because of ertain key advantages. First, Tanzania provides a valuable case study to examine irrigation water distribution, given that this is a strategic target of national water and irrigation management policies. Second, the potential for investigating spatial inequalities would have been limited in the Zimbabwean and Mozambican schemes given their small sizes. Third, the homogeneity in rice cultivation in the Magozi scheme in Tanzania greatly facilitates the study of yield variations – something that would be much more complex when considering a wide variety of crops, as occurs in the other schemes.

2.4.1 Fieldwork survey

The aim of the 2015 survey was to re-interview the same population sample as in 2014 in order to collect further information on water supply and economic inequalities. Human Ethics approval for the author’s fieldwork was granted by the ANU’s Chair of the Humanities & Social Sciences, on 11 November 2014.

The 2015 questionnaire included open and close-ended, as well as quantitative and qualitative, questions. Most of the questions were common for Kiwere and Magozi, while a few were tailored to the specific situation of each scheme. The interviews were designed to take approximately 45 minutes, hence limiting the number of questions to around 40 (44 in Kiwere and 36 in Magozi). A copy of the questionnaires is provided in Appendix A. Interviews were conducted with the aid of an interpreter who translated from English to Swahili and vice-versa. During the interviews, answers were recorded both on questionnaire print-outs and on an electronic database (Excel) using a tablet PC. With the consent of participants, interviews were audio-recorded. On average, five interviews were conducted each day, taking about one hour each, including presentations and greetings.

The list of questions was divided into four main sections. First, details on the interviewees were collected, such as name and location of irrigation plots. The name of the household representatives were checked against their respondent codes in order to associate the 2015 information to the 2014 baseline survey data. Also, names were verified against the land title registry to join the survey answers to spatial data (see Section 2.4.3 for details).

The second part of the questionnaire focussed on water supply and distribution. As further described in Section 4.2, it is uncommon for traditional irrigation systems to record water deliveries using mechanical flow-meters because of high costs and technical difficulties. Keeping this in mind, the initial plan was to obtain manual records on scheduling, timing of supply, operation of distribution gates, etc. During the first meeting with the local leaders of the IOs, it became clear that no such manual records existed. Therefore, without the objective data, a proxy measure was defined based on irrigators' perception of water supply and distribution. This was done by repeating questions 51 and 52 from the 2014 baseline survey on irrigators' level of water supply satisfaction and perception of equitable water distribution. The validity of using perceptions as a proxy for water supply is discussed in Chapter 4, on the basis of previous literature (Chambers 1988; Starkloff 2001). In the survey developed for this thesis, other water-related questions were included such as timing of water deliveries, quality of the irrigation infrastructure and the linkages between water supply and crop production.

In the last section of the questionnaire, the main objective was to explore the influences affecting socio-economic inequalities, with a particular focus on water distribution. Previous studies indicate disparities in crop yields and landholding as the two key mechanisms linking water supply and economic inequalities (Bardhan & Dayton-Johnson 2002; Bhattarai et al. 2002). In order to expand on such findings, open-ended questions were used to enable irrigators to freely express their own concerns.

2.4.2 Infrastructure observations

In each of the Tanzanian schemes, three days were dedicated to walk through and inspect the irrigation infrastructure to observe its functional condition and operation. A hand-held GPS device was used to take geo-coded pictures of all the irrigation structures and the canals at regular intervals (approximately every 50-100 m). Subsequently, pictures were imported into Google Earth and, subsequently, their location was exported into ArcMap 10.3.1. (Appendix B).

The type of infrastructure and levels of functionality and maintenance were noted for each canal and structure observations (Appendix B). There were two canal types: earthen and stone/concrete lined. Structures included gates, flow diversion structures and bridges. Based on their functionality, canal reaches were classified as 'functional' or 'defective' (adapted from Vermillion et al. (2000)). 'Functional' canal reaches were those in relatively good state and able to convey most of the desired flow with low water losses. Conversely, canal reaches were considered 'defective' if they presented significant issues interfering with the desired hydraulic operation, e.g. enlargement of the cross-section, collapse of the banks/side slopes, cracks to the lining or seepage. Following the methodology employed by Dayton-Johnson (1999), canal maintenance levels were rated by the author on direct observation as 'good', 'fair' or 'poor', based on the degree of cleaning (sediment built-up, presence of rocks, vegetation growth within the canal), grubbing (clearing of vegetation around the canals) and control of water filtration.

Similarly, structures were deemed 'functional' if they were able to perform their basic design function (Vermillion et al. 2000 p. 18) or 'defective' if they presented significant damage to the civil works (bridges) or inability to control flow as intended (gates and diversion structures). Structure maintenance was rated 'good', 'fair' or 'poor' depending on the degree of repairs, weed growth, siltation, etc.

2.4.3 Spatial data

During the 2014 dry season (June-November), a team of researchers for Ardhi University (Dar es Salaam, Tanzania) conducted geospatial surveys of the Magozi and Kiwere schemes. Geo-referenced information was then used to produce detailed maps depicting irrigation canals and farm boundaries (see Appendix C). Each farm plot was coded with an identification number and its size calculated using spatial analysis tools. Subsequently, the owner was identified and his/her name matched to the corresponding plot identification numbers. In this way, the Tanzanian researchers built a comprehensive cadastre that provided information on custodial ownership, size and specific location of all plots in the Kiwere and Magozi schemes.

Paper copies of the maps and land registries were used during personal interviews to facilitate discussion on water distribution and farm location. Also, digital maps were used to carry out spatial analyses with ArcMap 10.3.1 software (see Chapter 5 for details).

2.4.4 Policy investigations

Prior to commencement of the PhD fieldwork, a desktop review of Tanzania's water and irrigation policies was conducted, including the *National Water Policy* (2002), *Water Sector Development Strategy* (2006), *Water Resources Management Act* (2009) and *National Irrigation Act* (2013). While in Tanzania, in-depth interviews were conducted with a six government officials in the regional capital, Iringa, to get a better understanding of the policy aspects of irrigation water distribution. The two main irrigation water management government bodies with regional presence in Iringa are the Rufiji Basin Water Office and the Iringa District Council (see Chapter 6 for details). The interviews were conducted following the 'general interview guide' approach, as outlined by (Daniel 2010). This consisted of semi-structured questions, yet with a high degree of flexibility allowing the interviewer to adapt the questions based on the participants' responses.

2.5 Key data advantages

The data available for research in this thesis has several advantages that make them valuable for the study of water supply and economic inequalities. First, the data were collected at the household level across six smallholder irrigation schemes in SSA, which provides the opportunity to study inequalities at the local scale. As explained in Chapter 1, this contributes to filling the current literature gap at the micro level.

Second, data from open-ended questions provides insights into irrigators' perspectives on an issue that is associated with a number of other human and social factors. Thus, qualitative data collected during this thesis is a major strength of this research adding to the exiting literature on quantitative measures of inequality.

Third, data from various kinds and sources help to build a holistic, multi-disciplinary understating of water and economic inequalities. In particular, qualitative, numeric and spatial household data allow to conduct various types of analyses, and then, to compare and contrast the findings. Moreover, detailed infrastructure observations and policy information give an important perspective on technical and institutional issues – two critical constrains affecting water and irrigation management within traditional systems across the developing world.

2.6 Data gaps

The data used in this thesis have significant gaps due to two main reasons. First, the 2015 PhD survey did not to re-interview the entire population sample from the ACIAR baseline survey, resulting in a reduced number of observations. This was because a number of household representatives who participated in the 2014 survey could not be contacted or were away from the village at the time of the 2015 fieldwork. While other members belonging to the same household were searched for, in most cases, they were also not available. Thus, out of the 200 households interviewed in 2014, only 128 could be re-interviewed in 2015 (70 in Kiwere and 58 in Magozi). The loss of participants overtime can result in attrition bias, when drop-out individuals have unique characteristics associated with the variables of study (Hausman & Wise 1979). Non-parametric tests of statistical significance (Wilcoxon rank-sum and Kolmogorov-Smirnov) were applied to detect differences between “drop-out” and “retained” households (Miller & Hollist 2007). The tests showed no statically significant difference between both groups in relation to the variables of this study, such as household income, crop income, crop yields and water supply satisfaction, among others. Hence, it is reasonable to assume that irrigators re-interviewed in 2015 (see Chapter 4 and Chapter 5) are a random subset of all observations and not a subset with systematic differences that can be explained by other observed variables (Bhaskaran & Smeeth 2014).

To compensate for the loss of participants, additional interviews were conducted with 28 irrigators who had not been previously surveyed. These were selected following the same stratified random sampling approach based in the 2014 ACIAR survey. The data from these additional interviews was used in the study of irrigators’ perceptions (Chapter 4), but their application for regression analyses (Chapter 5) was limited because of the missing 2014 data.

The second data gap results from the difficulty in identifying plot owners and their location within the scheme. In most cases, matching survey and land registry data was straightforward as the household head was typically the landowner of the plots. However, in some instances, interviewees were unaware of the rightful landowner of the plots they cultivated. It also occurred that they were mistaken about the owner's official name, as the name they indicated did not appear in the land registry. As a result, from an initial sample of 200 households, only 126 could have their plot location identified (see Table 2-3).

Table 2-3 **Population sample sizes by year and data available**

Scheme	**Interviewed in 2014**	**Interviewed in 2015**			**Interviewed in 2014 and plot location identified**	**Interviewed in 2014, 2015 and plot location identified**
		Total	Re-interviewed from 2014 sample	Only interviewed in 2015		
Kiwere	100	80	70	10	69	58
Magozi	100	76	58	18	57	50
Total	200	156	128	28	126	108

2.7 Summary

This chapter describes the sources, content and limitation of the data used in this thesis. This PhD thesis is affiliated with an overarching research project in Zimbabwe, Tanzania and Mozambique funded by the Australian Government's ACIAR agency. Drawing from the project's support, the two main sources of data are:

1. 2014 Baseline survey conducted by African research partners as part of the ACIAR project. The data originates from a 65-question household survey carried out in May-July 2014 across six irrigation schemes in Zimbabwe, Tanzania and Mozambique.

2. 2015 Fieldwork data carried out by the author in Kiwere and Magozi schemes in Tanzania in May-August 2015. The information collected comprised: 1) detailed household face-to-face answers from two household surveys with around 40 questions each; 2) technical infrastructure observations; 3) spatial data (maps and land title registry); and 4) answers to in-depth interviews with government officials on water policy.

The data have two key limitations. First, there were no empirical, objective measures of water supply as IOs keep no record of water scheduling or infrastructure operations. Second, out of 200 participants in the 2014 survey, 62 were unavailable in 2015 and thus, only 128 were re interviewed. In addition, not all of the 2015 interviewees were able to identify the landowner's name in the title registry, which meant their answers could not be matched to spatial data. As a result of these data limitations, certain approaches to data analysis were not possible.

Chapter 3 Income inequality within smallholder irrigation schemes in Zimbabwe, Tanzania and Mozambique

3.1 Chapter objectives

This chapter analyses income inequality within the six irrigation schemes that are part of this PhD research. While national inequality statistics are readily available for Zimbabwe, Tanzania and Mozambique, broad-based figures are not necessarily representative of the situation at smaller scales, calling for a closer analysis at the micro (local) level (Ravallion 2001). The aim of this chapter is to provide an understanding of the levels and composition of economic inequalities within the Mkoba, Silalatshani, Kiwere, Magozi, 25 de Setembro and Khanimambo irrigation schemes. The findings of this chapter will serve as the basis for the rest of the thesis to investigate economic inequalities in further detail.

3.2 Introduction

It is estimated that 1.2 billion people across the world live in extreme poverty (UN 2013b). Alongside with growth, mitigating socio-economic inequalities is widely recognised as a key component of effective poverty reduction strategies (Groll & Lambert 2013; Kabubo-Mariara et al. 2012). As Bourguignon (2004) explains, these links are captured in the poverty-inequality-growth triangle given that:

> Poverty reduction in a given country and at a given time is fully determined by the rate of growth of the mean income of the population and the changes in the distribution of income (p. 2).

Without adequate redistribution interventions, rapid development can lead to excessive economic inequalities, often resulting in severe issues such as persistent poverty (Ravallion 1997), violent crime (Hsieh & Pugh 1993), corruption (Khagram 2005), political instability (Alesina 1996), worsened health (Kawachi & Kennedy 1997) and low education levels (De Gregorio & Lee 2002).

The poverty-inequality-growth triangle is especially crucial in rural areas, home to 70 percent of the developing world's extremely poor (Ferreira 1996; Ortiz & Cummins 2011; Watkins 2013). Sub-Saharan Africa (SSA), in particular, suffers from deep and persistent poverty and inequality, which undermines the gains from technological advances, including agriculture (Go et al. 2007). Most of the existing inequality literature is based on national or regional investigations (typically derived from governmental census), yet fewer studies exist at the level of villages or rural communities, where more detailed data collection is required (Silva 2013). As explained by (Ravallion 2001):

> Crosscountry correlations are clouded in data problems, and undoubtedly hide welfare impacts; they can be deceptive for development policy. There is a need for deeper micro empirical work on growth and distributional change. Only then will we have a firm basis for identifying the specific policies and programs that are needed to complement growth-oriented policies (p. 1807).

The analyses in this chapter are structured into three sections. First, income inequalities (Gini indices) are calculated at the local level (farming communities) and then compared to national figures. Second, a decomposition analysis is carried out by households' economic activity (agricultural or diversified) to assess the relative importance of the *between* and *within*-group components. Finally, a decomposition analysis by income source (agriculture, wages, business and self-employment and other) determines the relative contribution of each source to total inequality and identifies which sources have an 'equalising' or 'unequalising' effect.

3.3 Growth, poverty and inequality in sub-Saharan Africa

Between 1995 and 2012, SSA experienced an average annual GDP growth of 4.5 percent, accompanied by a 13 percent drop in the poverty headcount ratio (The World Bank 2017). Nevertheless, the sub-continent is still home to 30 percent of the word's extreme poor and undernourished population. After Latin America and the Caribbean, SSA is the second most income-unequal subcontinent, although with no clear trend over the last three decades (Ravallion 2014). Lesotho, South Africa and Botswana are the most unequal SSA countries, with Gini coefficients above 0.63, while Niger and Ethiopia have the lowest disparities, with Gini coefficients below 0.35 (CIA 2014).

Zimbabwe ranks among the ten most unequal SSA countries, with a Gini coefficient of 0.50 in 2006 (CIA 2014). Such economic disparities are partly derived from its agrarian socio-economic situation, still reflecting the legacy of the colonial era, the civil war and the reforms of the late 20th century. Throughout the 1980's and 1990's, Zimbabweans' livelihoods deteriorated significantly, as a result of repetitive droughts and issues associated with its land reform (Kinsey 2010; Mazingi & Kamidza 2011). The national poverty headcount ratio is 72 percent, while in rural areas it is 84 percent (ZIMSTAT 2013). Zimbabwe's Human Development Index (HDI) for 2012 was 0.397—in the low human development category—ranking 172 out of 187 countries and territories (UNDP 2013).

Tanzania is one of the four most income equal countries in SSA, with a Gini coefficient of 0.38 in 2007 (CIA 2014). Its economy is largely dependent on rural activities, with agriculture, hunting and forestry accounting for 27 percent of GDP, only second to the service sector (48 percent) (The United Republic of Tanzania 2013b). During the 1980s and early 1990s, Tanzania experienced significant economic growth, which brought poverty reduction, but also an increase in economic inequality (The World Bank 2011). Over the first decade of the 2000s, the average annual GDP grew by seven percent and the national HDI was lifted from 163rd to 151st position, on a world rank of 189 countries (UNDP 2011). The poverty headcount ratio across mainland Tanzania is 34 percent, whereas in rural areas it is 38 percent (The United Republic of Tanzania 2009a).

In Mozambique, income inequality is relatively high, with a 0.46 Gini index, above the SSA median of 0.43 (CIA 2014). Between 1995 and 2003, agriculture was the second largest contributor to GDP growth (1.7 percent out of 8.6 percent) and the main driver of poverty reduction. Over this period, agriculture experienced an average annual growth of 5.2 percent, yet this mainly represented a recovery after the 1977-1992 war, rather than productivity gains from innovation and investment (Virtanen & Ehrenpreis 2007). In 2008/09, the national poverty headcount ratio was 55 percent, with rural areas still being more affected (57 percent) than urban centres (50 percent) (Arndt et al. 2010). Worldwide, Mozambique is the tenth least developed nation, with a HDI of 0.393 in 2013 (UN 2014b).

3.4 Data

The data used in this chapter originate from the 2014 baseline survey, as described in Chapter 2. The analysis covers the six irrigation schemes in Zimbabwe, Tanzania and Mozambique that are part of the overarching ACIAR Africa project. An irrigation scheme can be defined as an area where crops are grown under irrigation (The United Republic of Tanzania 2013a). However, the idea of a 'scheme' often goes beyond physical and hydraulic infrastructure, to encompass social structure, such as rights, rules and procedures (Saldias et al. 2013). In this chapter, the term irrigation scheme is used to refer to the agricultural community whose members cultivate land within the same irrigated area, sharing the same water source and supply infrastructure.

The six schemes in this study range in size from 10 to 939 hectares, each of them having between 27 and 578 registered member households (Table 3-1). The average family landholding varies from 0.1 to 1.6 ha, in-line with average smallholder landholding at the respective national levels: 0.12 ha in Zimbabwe (FAO 2006), 0.9 ha in Tanzania (FAO 2015b) and 1.4 ha in Mozambique (FAO 2007). While there is not one consistent definition of smallholder farms, the most common approach it to classify them as those with less than two hectares of cropland (Hazell et al. 2007). Other usual smallholder characteristics include low-technology, reliance on household members for most of the labour and dependence on the farm as a principal source of family income (Nagayets 2005). All of these defining characteristics of smallholder farms are applicable to the six irrigation schemes examined in this chapter.

Table 3-1 **Characteristics of the irrigation schemes and surveys undertaken**

Country	Irrigation scheme	Total area (ha)	Number of irrigating households	Average household landholding (ha)	Surveyed households
Zimbabwe	Mkoba	10	75	0.13	68
	Silalatshani	110	212	0.52	100
Tanzania	Kiwere	189	199	0.95	100
	Magozi	939	578	1.62	100
Mozambique	25 de Setembro	38	38	1.00	25
	Khanimambo	16	27	0.59	9

Source: Rhodes et al. (2014)

Data used in this chapter include household revenues and expenditure over the 12-month period prior to the interview. Monetary figures were collected in each country's local currency, i.e. US dollars (USD) in Zimbabwe, Tanzanian shillings (TZS) in Tanzania and Metical (MZN) in

Mozambique. In this chapter, these figures are not converted into a common unit (e.g. USD) because the purpose of the analyses is to examine income inequalities *within* irrigation schemes and not *between* them. Income comparison across countries would require careful consideration of macroeconomic factors such as currency fluctuations, inflation, cost of living, consumer price indices, etc. (Ravallion 2001), which are outside of the scope of this thesis.

Information on the households' financial accounts were collected according to the source of revenue and type of expenditure (question 65, Appendix A), which were later aggregated into on-farm and off-farm categories (Table 3-2). Following the data check carried out during the review process (see Chapter 2), a subsequent investigation was conducted to detect possible abnormal values. Using summary statistics, calculation of extreme values and graphical tools, a number of observations were highlighted with income or expenditure figures that seemed inconsistent with the rest of the sample. Abnormal observations could be due to errors or to the household's particular characteristics. For example, unusually high expenses in crop inputs could be due to the household cultivating a very large area. After a detailed data review and consultation with in-country research staff, only one extreme value remained unexplained (income from irrigated crops for household mgz073 in Magozi, Tanzania). The influence of this observation was checked through a sensitivity test where levels and decomposition of income inequality in Magozi were computed with and without household mgz073. The results differed substantially, chiefly regarding the contribution of agricultural income to total inequality and its marginal effect. Given the unexplained nature of such high income value and its disproportionate impact on the analyses results, observation mgz073 was dropped from the population sample.

Table 3-2 **Revenue and Expenditure categories used in household survey**

	Revenue	Expenditure
On-farm	Rainfed crops	Crop inputs
	Irrigated crops	Harvesting/transport
	Livestock sales	Livestock inputs
	Milk sales	Hired labour
	Other	Irrigation
		Other
Off-farm	Agricultural labour	Food
	Non-agricultural labour	Education
	Regular employment	Health
	Business/self-employment	Social events
	Remittances	Housing
	Seasonal work	Personal transport
	Other	

3.5 Analytical framework

Economic inequality can be defined in many ways, but it is typically considered to be the uneven distribution of wealth, income and/or assets among individuals of a group, or between groups of individuals (McKay 2002). The preferred indicators of poverty and living standards tend to be money-metric, i.e. income or consumption expenditure (Sahn & Stifel 2003). Alternative non-monetary measures exist, such as asset ownership (Filmer & Pritchett 2001; McKenzie 2005) and the Multidimensional Poverty Index, which combines education, health and living standards indicators (Alkire & Santos 2011; Kovacevic & Calderon 2014). In this chapter, monetary indicators were used to compare local and national inequalities and to investigate how various income sources contribute to total inequality. Out of a wide range of inequality measures, the section below presents a summary of the two selected indicators: Gini coefficient and Theil index.

3.5.1 Gini coefficient

The Gini coefficient measures the extent to which the distribution of wealth within a group deviates from a perfectly equal distribution, with its values ranging from 0 to 1 (The World Bank 2011). Its advantages include it being commonly used and relatively easy to calculate; having a visual representation and allowing comparison between different size populations.

The Gini coefficient can be estimated based on the representation of the Lorenz curve, plotting cumulative income vs. cumulative population. It can also be mathematically calculated as follows:

$$G = Cov(y, F(y))\frac{2}{\bar{y}} \tag{3.1}$$

where *Cov* is the covariance between income levels *y* and the cumulative distribution of the same income *F(y)* and $\bar{y}$ is average income.

Lerman and Yitzhaki (1985) developed a method to decompose the Gini coefficient as the sum of the inequality contribution of each income source, such that:

$$G = \sum_{k=1}^{k} R_k \, G_k S_k \tag{3.2}$$

where, S_k is the share of income source *k* in total income, G_k is the Gini coefficient of income source *k* and R_k is the Gini correlation of income from source *k* with the distribution of total income. By calculating partial derivatives of the Gini coefficient with respect to a percent change *e* in income source *k*, it is possible to estimate the percent change in total inequality resulting from a small percent change in income source *k:*

$$\frac{\partial G/_{\partial e}}{G} = \frac{R_k G_k S_k}{G} - S_k \tag{3.3}$$

This property is particularly useful in this study because it allows for the identification of equalising or unequalising effect of each income source on total inequality (López-Feldman 2006).

The Gini coefficient also has several limitations. Firstly, it does not satisfy the properties of aggregativity and additive decomposability (Bourguignon 1979 p. 902), thus limiting its ability to analyse inequality *between* and *within* population subgroups. Moreover, in presence of negative incomes, the Gini coefficient presents abnormal behaviours, as detailed in Section 3.6.

3.5.2 Theil Index

The Theil Index is a specific case of the generalised entropy indices (Bellù & Liberati 2006). Its lower value is zero (perfect equality) and it has no upper limit. The index is defined as follows:

$$T = \frac{1}{n}\sum_i \left(\frac{y_i}{\bar{y}}\right) \ln\left(\frac{y_i}{\bar{y}}\right) \tag{3.4}$$

where y_i is the i observation and $\bar{y}$ is the average income.

One of its key advantages is being decomposable and additive into groups, thus allowing distinction of *between* and *within* sub-group inequality components. Assuming m groups, the Theil Index is decomposed as follows:

$$T = \sum_{k=1}^{m} \left(\frac{n_k}{n}\frac{\overline{y_k}}{\bar{y}}\right) T_k + \sum_{k=1}^{m} \frac{n_k}{n}\left(\frac{\overline{y_k}}{\bar{y}}\right) \ln\left(\frac{\overline{y_k}}{\bar{y}}\right) \tag{3.5}$$

where the first term and second terms are, respectively, the *within* and *between-group* components. Similarly, the Theil index can also be decomposed by source of income, following the expression for m sources:

$$T = \sum_{k=1}^{m} \frac{1}{n}\sum_{i=1}^{n} \left(\frac{{y_i}^k}{\bar{y}}\right) \ln\left(\frac{y_i}{\bar{y}}\right) \tag{3.6}$$

In this study, the decomposition of the Theil Index in *between/within sub-groups* and *by income source* was calculated by computing equations (3.5) and (3.6).

The Theil Index has also some drawbacks, such as not having an intuitive representation and not being suitable to compare populations of different sizes. Further, it does not support non-positive values, as $\ln x$ is undefined for $x \leq 0$. As explained by Bellù and Liberati (2006) and Vasilescu et al. (2011), the limitation of zero values can be overcome by replacing zeros with very small values $\varepsilon > 0$, such that $I_{Theil}(x_1, \ldots, x_{n-1}, 0) \equiv I_{Theil}(x_1, \ldots, x_{n-1}, \varepsilon)$. In this chapter, ε was taken equal to 10^{-10}.

3.6 Negative incomes and measures of inequality

Two common measures of agricultural income are net cash income and net farm income. The former is a measure of cash flow representing the money available for debt repayment, investment or withdrawal (Statistics Canada 2000), while the latter is a value of farm production including cash and non-cash transactions (Edwards 2013). Net farm income could not be used in this chapter because there were no records of non-monetary income transactions, e.g. depreciation, income in-kind or commodities stored. Therefore, net cash income was chosen as the measure of household income from farm sources. Omission of non-cash transactions may impact the estimate of income inequality (Deininger & Olinto 1999), particularly within communities heavily reliant on the informal economy. While the poor and women may have a larger share of non-cash incomes (FAO 1986; Sarris et al. 2006), the wealthy would have greater business expenses such as asset depreciation and in-kind payments.

Across the six irrigation schemes, 30 percent of the households reported higher on-farm expenses than on-farm revenues, thus resulting in negative net cash incomes from farming activities. Negative incomes pose a major constraint in the study of inequality, which has been discussed in the literature with different authors adopting different approaches.

Walker and Ryan (1990) and Möllers and Buchenrieder (2011) note the existence of negative incomes in their data, yet neither discuss the implications or treatment methods for inequality calculation. Schutz (1951) and Stich (1996) indicate that the exclusion of negative incomes is a common method to deal with negative incomes in the measurements of income inequality. Examples of the application of this method include Cowell (2008), Cribb et al. (2013) and Sanmartin et al. (2003).

Disregarding households with negative net cash incomes is not an ideal methodology for this study because it would ignore almost one-third of the sample. Furthermore, this approach is undesirable for agricultural redistribution policies given that it is normal for farms to record losses (Allanson 2005), and thus, it misses out on a key feature of household incomes (Rawal et al. 2008).

It is possible to calculate the Gini coefficient including zero and negative values, yet, the resulting modified coefficient violates several of its basic properties. Firstly, the principle of transfers (Dalton 1920), by which a transfer of income from a richer individual to a poorer one leads to a reduction in income inequality, is not always satisfied when the Gini coefficient includes negative incomes. Moreover, the modified Gini coefficient is no longer bounded between 0 and 1, making it inaccurate as a measure of comparison across populations or time. Appendix D provides a theoretical and empirical demonstration of why negative incomes violate the basic principles of the Gini index, thus limiting its application in decompositions analysis.

In an attempt to overcome the limitations imposed by negative incomes, Chen et al. (1982) proposed a reformulation, referred to as normalisation, which was subsequently refined by Berrebi and Silber (1985). As shown by Raffinetti et al. (2014), this normalised Gini presents abnormal behaviours, such as providing the same inequality measure for two populations having completely different income distributions (total equality and total inequality). Furthermore, it does not allow for an accurate decomposition by income source (Mishra et al. 2009).

The Australian Bureau of Statistics (ABS 2006) argues that negative incomes often reflect the households' business and investment arrangements or may be a result of accidental or deliberate underreporting. Therefore, it is inappropriate for them to have a disproportionate influence on inequality measures. Following this argumentation, the *equivalisation* method is proposed, by which individual income components with negative values are set to zero before computing the total income of each household (OECD 2014). The process of *equivalisation* has been defined by the OECD and is used by government agencies such as the Australian Bureau of Statistics (ABS 2006) and the UK Department for Work & Pensions (2014). This technique of truncating the data to report negative incomes as zeros has been applied by Seidl et al. (2012) and Bray (2014), who showed consistency of results using various ways of treating negative incomes.

When it comes to adopting one method or another, Smeeding et al. (1990) state that each researcher is left to deal with zero and negative incomes as he or she sees fit. Similarly, Deaton (1997) notes that the choice of inequality measures can be made based on practical convenience or theoretical preference.

Given the interest to maintain all households in the sample and to use the Gini and Theil indices, the *equivalisation* process is deemed to be the most suitable approach to deal with negative incomes in this chapter. Thus, negative farm incomes were converted to zero, before being added to other income components to obtain the total. In order to test the adequacy of the chosen method, a sensitivity analysis is conducted in Appendix E.

3.7 Results and discussion

3.7.1 Income inequality at scheme and national levels

This section describes the levels of economic inequality within six smallholder agricultural communities and compares them to their respective national figures. Household consumption expenditure and income were used at the scheme level, while family income served as the national indicator, given the available country statistics (Table 3-3).

Table 3-3 **Inequality at scheme and national levels**

		Scheme level		**National level**
Country	**Scheme**	**Consumption expenditure Gini**	**Income Gini**	**Income Gini**
Zimbabwe	Mkoba	0.54	0.60	0.50
	Silalatshani	0.47	0.48	0.50
Tanzania	Kiwere	0.54	0.60	0.38
	Magozi	0.39	0.56	0.38
Mozambique	25 de Setembro	0.59	0.65	0.46
	Khanimambo	0.55	0.58	0.46

Source: Author’s computations for scheme level and CIA (2014) for national levels.

Inequalities measured by expenditure are smaller than by income, which is common given that consumption expenditure tends to be more evenly distributed than income (Aguiar & Bils 2011; Finn et al. 2009; Krueger & Perri 2006). Income inequalities at scheme level are generally higher than at national levels. The greatest difference is in Tanzania, where Gini income coefficients within the agricultural communities are in the order of 50 - 60 percent higher than at the national scale.

The Tanzanian Ministry of Finance and Economic Affairs (The United Republic of Tanzania 2009a) argues that, given the country’s relatively low levels of inequality, income redistribution is not likely to be effective in achieving significant poverty reduction. Instead, it suggests that continued high rates of economic growth over the long-term will be required. By contrast, the results of this study show that significant income inequalities exist at smaller scales, which are currently being overlooked by country-wide statistics.

3.7.2 Income dualism between agricultural and diversified sources

In rural developing areas, non-agricultural earnings represent an important part of households' incomes, but they can also create significant economic inequalities (Barrett et al. 2001b; Escobal 2001; Reardon 1997). Hence, the aim of this section is to analyse income differences *between* and *within* two households groups, namely: i) those earning incomes exclusively from agriculture (including farm income and agricultural labour); and ii) those having diversified incomes (including non-agricultural labour, regular, seasonal or self-employment, business, remittances and other).

Non-parametric tests of statistical significance, Wilcoxon rank-sum (WRS) and Kolmogorov-Smirnov (K-S), were used to analyse differences in the distribution of incomes between population subgroups. Common parametric tests could not be used because they require making assumptions on parameters characterising the populations' distributions, which was not possible given the data available for this study.

In Zimbabwe, the vast majority of households have diversified incomes, while in Tanzania and Mozambique, only half obtain earnings outside of agriculture (Table 3-4). One common characteristic to all six communities is that households who make a living exclusively from agriculture had consistently lower mean and median incomes than those with diversified incomes. The results of the WRS and the K-S tests conclude that the distribution of income is not the same in both groups and that exclusively agricultural households' rank lower in the overall income distribution. The WRS test ($p < 0.10$) indicated that the null hypothesis that incomes of agricultural households are not different from diversified-income households could be rejected. Similarly, the K-S test concluded that ($p < 0.10$) the hypothesis that both groups have the same distribution was also rejected in all schemes, except for Magozi.

Table 3-4 **Income statistics by type of income**

Scheme	**n**		**Mean HH Income†**		**Median HH Income†**		**Wilcoxon rank-sum test**	**Kolmogorov-Smirnov test**
	Ag	Div	Ag	Div	Ag	Div	Z	D
Mkoba	6	62	179	1,098	67	475	-2.52**	0.66***
Silalatshani	20	80	411	940	180	700	-3.55***	0.48***
Kiwere	56	44	1,006	2,026	436	1,203	-3.29***	0.43***
Magozi	48	51	1,500	2,905	1,007	1,458	-1.79*	0.20
25 de Setembro	14	11	40,634	187,707	27,930	84,000	-2.63***	0.55**
Khanimambo	4	5	5,250	177,610	0	173,200	-2.49**	1.00**

The values are statistically significant at ***p < 0.01, ** p < 0.05, * p < 0.10
† Mkoba, Silalatshani in USD; Kiwere, Magozi in ‘000 TZS; 25 de Setembro, Khanimambo in MZN
Ag: exclusively agricultural income household; Div: diversified income households

Despite the remarkable contrast *between* agricultural and diversified income households, the Theil Index decomposition reveals that disparities *within* these two groups are actually the main contributor to overall inequality (Table 3-5). The only exception is Khanimambo, yet results from small samples should be interpreted with caution, given the low power of statistical tests (see Section 3.8).

Table 3-5 **Household income analysis and decomposition by activity group**

Scheme	**Percentage of Ag HH**	**Percentage of Div HH**	**Gini coefficient**		**Theil Index decomposition (percent of total)**	
			Ag	Div	Within	Between
Mkoba	9	81	0.59	0.58	92	8
Silalatshani	20	80	0.49	0.45	91	9
Kiwere	56	64	0.59	0.69	90	10
Magozi	48	52	0.55	0.59	92	8
25 de Setembro	56	44	0.64	0.43	72	28
Khanimambo	44	56	0.56	0.54	27	73

Ag: exclusively agricultural income household; Div: diversified income households

These results show that households with diversified earnings have higher incomes than those exclusively dedicated to agriculture, which is consistent findings elsewhere in Africa (Barrett et al. 2001a). As a result of entry barriers, poor households typically struggle to access highly-profitable non-farming activities, whereas more advantaged families tend to profit from greater returns, thus creating a negative feedback loop between poverty, inequality and diversification (Barrett et al. 2001a; Woldenhanna & Oskam 2001). Furthermore, the findings in this section contribute to the existing literature by showing that the contrast *between* diversified and non-diversified income households only explains a minor portion of overall income inequality, while, inequalities *within* each group are, in fact, the major driver.

3.7.3 Relative importance of income sources in total inequality

An extensive literature review by Senadza (2011) concluded that, to better understand the effects of income on inequality, it is important to distinguish between the various components of non-farm income. Hence, this section analyses the effect on total inequality derived from four distinct income sources: i) *agricultural*, including on-farm income and agricultural labour; ii) *wages*, including non-agricultural labour, regular employment and seasonal work; iii) *business and self-employment;* and *iv) other*, including remittances and other unspecified sources.

In Tanzania, agriculture is the most important source of income, accounting for three-quarters of total earnings and circa 80 percent of inequality (Table 3-6). In Mozambique, agriculture and wages account for over 90 percent of income and inequality. Conversely, Zimbabwean schemes rely more heavily on other sources (mainly remittances), which also account for the largest portion of total income inequalities. On a national level, it is estimated that over three million Zimbabweans – a quarter of the total population – live in diaspora (Bracking & Sachikonye 2010) and that their remittances sum up to USD 900 million– equivalent to almost two percent of the country's GPD (Mishi & Mudziwapasi 2014).

Table 3-6 **Income and inequality decomposition by source (percent)**

Scheme	**Agriculture**		**Wages**		**Business and self-employment**		**Other**	
	Income Share	**Inequality Share**	**Income Share**	**Inequality Share**	**Income Share**	**Inequality Share**	**Income Share**	**Inequality Share**
Mkoba	19	2	15	23	14	17	52	58
Silalatshani	34	14	17	42	5	3	44	42
Kiwere	79	83	7	6	11	9	3	1
Magozi	66	43	9	15	23	42	2	0
25 de Setembro	46	10	47	86	6	4	1	0
Khanimambo	52	48	43	47	5	5	0	0

A key rationale for understanding inequality and formulating policies is to investigate how changes in a particular income source affect overall inequality (Shariff & Azam 2009; Singh & Dey 2010). In order to answer this question, a Gini decomposition following equations (3.2) and (3.3) was carried out. For each income source, the results summarised in Table **3-7** indicate the marginal effect on total inequality due to a one percent increase in that particular source, while holding all other sources constant. The direction and magnitude of the marginal impact are given by the *% Change*. A negative sign indicates a tendency to reduce total inequality, while a positive sign reveals an unequalising effect. To test the statistical significance of the marginal impacts, 99, 95 and 90 percent confidence intervals were calculated using bootstrapping techniques.

Table 3-7 **Gini decomposition by income source and marginal effects**

Scheme	**Agriculture**		**Wages**		**Business and self-employment**		**Other**	
	Gini	% Change	Gini	% Change	Gini	% Change	Gini	% Change
Mkoba	0.76	-0.07***	0.93	0.02	0.92	0.02	0.76	0.04
Silalatshani	0.68	-0.07**	0.94	0.10**	0.91	-0.01	0.70	-0.01
Kiwere	0.66	0.01	0.94	0.00	0.92	-0.01	0.92	-0.01
Magozi	0.57	-0.09**	0.95	0.02	0.91	0.08*	0.96	-0.01*
25 de Setembro	0.54	-0.13***	0.90	0.13**	0.91	0.01	0.90	-0.01***
Khanimambo	0.61	-0.06	0.69	0.06	0.75	-0.01	N/A	N/A

Note: The values are statistically significant at *** $p < 0.01$, **$p < 0.05$, *$p < 0.10$

In four out of six schemes (Mkoba, Silalatshani, Magozi and 25 Setembro), agriculture has an equalising effect that is statistically significant. Conversely, wage incomes have an unequalising effect across the six schemes, although only two schemes (Silalatshani and 25 de Setembro) showed statistical significance. Little can be said about the effect of business and self-employment, as the marginal impacts are mixed across the various schemes and only statistically significant in Magozi. Other income sources have mainly an equalising effect, with statistically significance in Magozi and 25 de Setembro.

A literature review undertaken by Lay et al. (2008) on the equalising or unequalising effect of non-agricultural incomes concluded that the results of various studies were mixed and seemingly contradictory. These inconsistencies, similar to the ones found in this study, could be reconciled by further investigating the underlying drivers of inequality that are specific to each income source.

3.8 Limitations

This study has three major limitations. First, the populations of study consist only of members of irrigation schemes, but not the entire rural communities. This is because the data available for this study were collected as part of the ACIAR-funded project focused on irrigated agriculture (ACIAR 2013) that did not include dryland farmers or non-farmers. To allow adequate probably sampling across the entire community, more extensive surveys would be required that were out of the scope of the ACIAR project and this thesis. If more data were to become available, future research could be extended to examine differences in income and inequality within the entire rural communities, particularly comparing irrigators and non-irrigators, as well as farmers and non-farmers.

The second limitation is the large proportion of households reporting negative net cash incomes from farming activities. It is possible that farm earnings were underreported and expenses over-reported, either accidentally or deliberately. Therefore, an improvement could have been made by identifying negative farm incomes during the interviews to then question participants about their financial losses. This would have improved the accuracy of the records and provided greater insight into why certain households experience negative incomes.

The third limitation is the small population samples in Mozambique ($n < 30$), which undermines the robustness of statistical significance tests and can result in the underestimation of the Gini coefficient (Deltas 2003). This problem was partially addressed by using non-parametric tests, which are preferred for small samples (Vickers 2005). An alternative approach would have been to remove Mozambique from the study, yet it was a deliberate choice to use the six irrigation schemes, as an exercise to examine income inequalities within small communities. The fact that reduced sample sizes have important limitations for mathematical analyses, does not mean that small communities should be excluded from the study of economic inequalities. Indeed, these schemes represent an important research opportunity at the local (micro) level, which has been widely overlooked by previous literature dominated by inequality analyses at national and international (macro) scales.

3.9 Conclusions

This chapter analyses income inequality within six smallholder irrigation schemes in Zimbabwe, Tanzania and Mozambique using household survey data from 2014. The Gini and Theil indices are used to measure income inequalities and their decomposition by activity sector and source.

The results indicate that income inequalities within the irrigation schemes are considerably higher (20 to 60 percent) than their respective countrywide figures. Moreover, across the six schemes, exclusively agricultural households earn consistently lower incomes than those with diversified incomes. In Tanzania, the largest source of income and inequality is agriculture, while in Zimbabwe other sources (including remittances) are predominant. In four out of the six irrigation schemes, agriculture has an equalising effect, whereas non-agricultural incomes had mixed effects that generally lack statistical significance.

These findings in chapter 3 have important policy implications. First, it is crucial to recognise the existence of high levels of income inequality at small scales. Thus, national or broad-based strategies to reduce poverty and inequality should be carefully examined before being applied within local contexts, as they could overlook existing inequalities and thus perpetuate, or even worsen, economic inequalities. Policies incorporating income distribution considerations at local scales would be more effective in achieving poverty reduction, rather than those targeting only broad-based economic growth.

Second, strategies aimed to lower inequality levels within smallholder irrigation schemes should be two-fold. On the one hand, removal of entry-barriers and diversification into more gainful, non-farm activates could help lift the income of poor, exclusively-agricultural households. On the other hand, it is also crucial to address inequalities existing *within* activity groups. One possible approach would be to target development efforts to those households who are most seriously affected by poverty within each activity group.

Finally, because agriculture tends to have an equalising effect on income distribution, increasing farming productivity could also contribute to reducing income inequality in some cases. Nevertheless, it is crucial to bear in mind that results from a certain community should not be generalised to larger extents without the appropriate evidence.

Chapter 4 Perceptions of Tanzanian smallholder irrigators on water supply and economic inequalities

4.1 Chapter objectives

Chapter 3 showed that significant income inequalities exist within the six irrigation schemes studied in this thesis. Furthermore, within the Kiwere and Magozi schemes in Tanzania, agricultural incomes are the largest driver of inequality. One of the hypotheses of this thesis is that inequity in irrigation water supply aggravates socioeconomic disparities, as suggested by previous studies, in South Asia (see Sections 1.3 and 4.2). The aim of Chapter 4 is to test this hypothesis on the Kiwere and Magozi irrigation schemes by undertaking a qualitative study of irrigators' perceptions on water and socioeconomic inequalities.

As pointed out in Chapter 2, the absence of physical quantitative measures of water supply led to the use of irrigators' perceptions as an indicator of inequities in water supply. This approach is not only closer to irrigators' understating of water management, but it also provides an insight into possible drivers for collective action. Thus, key research questions in this chapter are: What are the perceived reasons for inequities in water supply? What are the perceived mechanisms linking water supply and economic inequalities? Are such perceived mechanisms reflected in quantitative measures of agricultural production?

4.2 Literature review

The issue of distribution of water is regarded as one of the most critical challenges of the 21st century, especially in water scarcity situations (Boelens & Dávila 1998; Maskey et al. 1994). Equitable access to water resources appears to be a major objective on all water management levels (Wegerich 2007) and stands as one of the three pillars of IWRM, given its importance for human welfare and development (Peña 2011). On a global scale, irrigated agriculture is by far the single largest water user, accounting for 70 percent of freshwater withdrawals (UN 2016).

In developing countries, irrigation is widely recognised as a key strategy for rural development and poverty reduction (Chitale 1994; Makombe & Sampath 1998). Furthermore, a growing body of literature raises fundamental questions on the linkages between irrigation, equity and social justice (Giordano & de Fraiture 2014; Gorantiwar & Smout 2005; Van Den Berg & Ruben 2006). Bhattarai et al. (2002 p. 27) explain that, because irrigation civil works are mostly publicly funded, there is an inherent responsibility to ensure that its derived benefits 'should be distributed, as far as possible, equally among all members of society'. Swyngedouw (2006 p. 15) argues that water supply and socioeconomic inequalities are interconnected because 'controlling water generates considerable social power, while the latter permits re-enforcing or extending this control'. This relationship becomes more acute for agricultural systems that are dependent on hydraulic infrastructures (Ibid.). Within the context of sub-Saharan Africa, Conceição et al. (2016) note that agricultural productivity is a key pathway for equitable generation of income and that equitable water distribution is crucial to achieve such gains.

Importantly, Sharma et al. (2008) argue that improper irrigation water overuse is an major factor contributing to income inequality, but that equity of supply has not been sufficiently addressed by irrigation impact studies. On a similar line, Bhattarai et al. (2002 p. v) point out that 'a little explored topic is how exactly irrigation infrastructure affects inequalities in income distribution'. In fact, most of the existing literature revolves around three key points, with little exploration into other dimensions.

First, empirical studies on irrigated agriculture tend to associate water inequities to inequality in landholding (Bardhan 2000; Dayton-Johnson 2000b; van Etten et al. 2002) and yields (Maskey et al. 1994; Ostrom 1993). Adding to the extensive body of literature, Bhattarai et al. (2002) note a connection between water access and government services yet such association is theoretical rather than empirical. Conversely, other possible linkages – human, social, institutional − remain largely unexplored.

Second, the geographical scope of previous studies is typically at a large scale. Examples of studies of water equity within river basins include Kolberg (2012) − Guadalquivir, Spain; Wegerich (2007) −Amu Darya, central Asia; Silva (2013) − Limpopo, Mozambique; Cullis and van Koppen (2007) − Olifants, South Africa; and van Koppen et al. (2004) − Rufiji River, Tanzania. Other studies have compared water access disparities across various schemes belonging to a common geographical region, e.g. Saldias et al. (2013) − Abanico Punata, Bolivia; Bardhan and Dayton-Johnson (2007) −Tamil Nadu, India and Guanajuato, Mexico;

Makombe and Sampath (1998) – Zimbabwe; and Anwar and Ul Haq (2013) − Punjab, India. Only a few studies − most of which are in South Asia − investigate inequities in water distribution within small traditional irrigation schemes using an empirical approach. For example, Lal Kalu et al. (1995) examines equity and efficiency in water distribution within a 1,000 ha irrigation area in Nepal. However, the study does not estimate actual levels of inequity, but rather proposes various theoretical water management scenarios to evaluate their impact on equity of supply. In a similar study of a *warabandi* system in Punjab, Pakistan, Sharma and Oad (1990) employ mathematical calculations to assess various time-allocation rules aiming for equity of water distribution. However, this study does not discuss the implications of water inequality for socioeconomic or production disparities within the irrigation community. Similarly, Maskey et al. (1994) evaluate time-allocation and yield inequalities along hydraulic gradients (head vs tail) of two small Nepali irrigation schemes. While frequency of irrigation is greater in the upper sections than in the lower ones, the association with crop production remains unclear as differences in paddy yields are not statistically significant across reaches.

The third point of commonality among previous studies on equity of water supply is the use of quantitative measures (e.g. volumes, depths, flows, etc.) and mathematical calculation of indices such as the Gini coefficient, Theil Index, Atkinson Index, coefficient of variation and interquartile ratio (see Chapter 6 for details). Although reliable measures of inequity are extremely important for effective policy making (Sampath 1988), such sophisticated methods are highly compromised by lack of adequate data, chiefly in low-technology irrigation schemes. In fact, metrics to quantify water are far removed from routine practices of traditional farmers', whom rather think of their water supply in terms of *morning/afternoon*; *start/end of the season*; or *canal clear/blocked*. In an example taken from the Kimani rice-growing scheme in Usangu, Tanzania, Lankford (2006 p. 354) notes that tail-enders felt top-enders were wasteful because their water 'should be ankle depth, whereas they take more'.

The most obvious and common measure of irrigation water supply is quantity, expressed in terms of volume (Bos 1997; Kolberg 2012) or depth (Anwar & Ul Haq 2013; Bird 1991; Lal Kalu et al. 1995). Despite its clear advantages, flow metering remains largely inaccessible for most traditional irrigation systems due to technical limitations (e.g. irregular canal cross-sections) and high maintenance and readings costs. In fact, the lack of data on volumes is a major obstacle for water allocation and management in Tanzania. As noted by van Koppen et al. (2007), in Tanzania, it is only in large-scale, highly-controlled systems that volumes can be sufficiently known and regulated. Other technical measurement tools also exist, such as remote sensing (Ahmad et al. 2009), yet they pose similar operational and cost issues for their widespread application in traditional systems.

In the absence of direct measurements of water supply, various proxy indicators can be found in the literature, e.g. number of irrigations multiplied by area (Makombe & Sampath 1998), frequency of irrigation (Maskey et al. 1994; Saldias et al. 2013) and presence/absence of wet land (Malhotra et al. 1984; Sampath 1988). When no systematic, quantitative data is available, location of farms within the schemes is typically used as an indicator of supply. This approach follows the assumption that head-end plots are better off in terms of quantity and reliability of water supply compared to tail-end ones. Nevertheless, distance to the head is not always a good predictor of water supply (Merrey 1997) as it ignores location heterogeneities along the secondary and tertiary canals (i.e. distance from farm to channel outlet).

Besides volumetric measures of water supply and other quantitative proxies, irrigators' perceptions are increasingly recognised as valuable indicators of water supply and equity (Chambers 1988). In Tanzania, the widespread lack of objective data leads water officers to rely on their subjective judgment in the collection of volume-based rates (van Koppen et al. 2004). Tisdell (2003) notes that perceptions of basic liberties and distributive justice are at the core of water disputes. Taking into account irrigators' perspectives on water distribution is especially relevant for cooperation and conflict avoidance. For example, Starkloff (2001) takes into consideration irrigators' perceptions on water-related issues as a determinant of social mobilisation for participatory water management. In particular, the author analyses perceptions' about the state of water distribution by asking irrigators about their level of satisfaction.

Theories of social action (Kawakami & Dion 1995) argue that perceptions of inequality (e.g. feelings of discontent and injustice) are recognised as an important predictor of individual and collective behaviours, including social protest and political violence. Mine et al. (2013 p. 168) indicate that 'perhaps more so than the actual inequality, it is *perceptions* of inequality that can be the drivers of conflict'. Furthermore, understanding of how people perceive their problems (such as inequality) is also crucial to developing management regimes that will improve their lives and their environment (Quinn et al. 2003).

4.3 Research methodology

The research approach used in this chapter is mixed-methods; a combination of qualitative and quantitative methods (Creswell & Clark 2007). Data related to irrigators' perceptions and views were collected using (open and closed-ended) qualitative questions, whilst measurable factors (e.g. crop production and land size) were evaluated using a quantitative approach. Information relative to the operability and maintenance of the irrigation infrastructure was collected through direct observation (see Section 2.4.2).

4.3.1 Qualitative data analysis

Closed-ended qualitative questions were formulated using Likert-type rating scales. Most questions applied a 3-point scale, which is considered suitable when studying group behaviour (Lehmann & Hulbert 1972) and adequately reflects the directional component of the answers (Jacoby & Matell 1971; Peabody 1962). The questions regarding water supply equity and satisfaction applied a 5-point Likert scale to be consistent with other data collected during the 2014 survey. For the purpose of this paper, responses were converted to a 3-point Likert scale where positive and negative replies were grouped at each side of neutral. This is justified given that the focus of this chapter is the directional component of a Likert-type scale, which is adequately reflected in trichotomous scales (Jacoby & Matell 1971; Peabody 1962). Conversely, a 5-point scale captures better the intensity components, as applied in regression analyses in Chapter 5.

Open-ended questions were used to gain greater insight about more complex issues. Participants were asked to describe, in their own words, the reasons causing inequities in water supply and the mechanisms whereby equitable water distribution could help reduce the wealth gap within their communities. Subsequently, thematic analyses was conducted where narrative responses were synthesised into groups of information (themes) representing common ideas (Boyatzis 1998). While there is no formal restriction on the number of themes, Creswell (2013) and Lichtman (2012) indicate that, even in large datasets, qualitative information shall be categorised into five to seven mean concepts.

In-depth interviews were also held with key informants to discuss specific topics that required further information. This method is often used to provide context to other data, offering a more complete picture of what has already been observed and why (Boyce & Neale 2006).

No quantitative data were available regarding water supply within the schemes (see Section 4.4 for details). To overcome this limitation, a qualitative proxy was used, based on irrigators' perception of their adequacy of water supply considering a range of aspects, such as volumes, timing and reliability. This method has been adapted from Starkloff (2001 p. 31), who applied it in a study of irrigators' perceptions in Pakistan where 'respondents were asked about their level of satisfaction with the prevailing system of water distribution in their distributaries'. Similarly, Pasaribu and Routray (2005) investigates irrigators' perceptions of water supply (adequacy, reliability, timeliness and fairness of distribution) and uses tests of statistical significance to explore asymmetries in irrigation schemes in Indonesia. More recently, Williams and Carrico (2017) use self-reported levels of satisfaction with irrigation water to differentiate between water-stressed and water-secure irrigators in Sri Lanka. Characterises of water-stressed households are then investigated through regression analysis to understand factors influencing rice yields and drought adoption strategies.

4.3.2 Quantitative yields and yield gap analyses

Yield and yield gap analyses were conducted for the Magozi scheme using paddy rice production data. These investigations were only carried out for Magozi, given the system's relative homogeneity of crop production and ease of analysis. Conversely, in Kiwere irrigators grow varying combinations of horticultural crops (garlic, tomatoes, onions, fruits, etc.) throughout the year. This makes it very difficult to obtain an accurate measure of farm yield that would allow a fair comparison across the entire Kiwere scheme (see Section 5.5.2). Moreover, the direct impact of water on horticultural crop production is difficult to evaluate, as there are many other influencing factors such as fertiliser use, seasonality, agronomic practices, etc. By contrast, in the Magozi scheme, rice is virtually the only irrigated crop, it is cultivated without chemical fertilisers (Rhodes et al. 2014) and is harvested once a year, between April and May. The interviews in Magozi were conducted between May and June 2015, thus allowing irrigators to provide information relative to the latest irrigation season (December 2014-May 2015).

Interviewees in Magozi were asked to report on their paddy rice production, sown and harvested areas. *Actual yields* (Y_A in kg/ha) were calculated as output over harvested area (FAO and DWFI 2015). A large number of irrigators reported they had not been able to harvest the entire area they had cultivated (sown) due to inadequate water supply. The situation where cropland is not harvested due to lack of adequate inputs, meteorological conditions or other factors is often referred to as land failure or crop failure (FAO 2002). Hence, the difference between total sown and harvested area was defined as *failed area* and is reported as a percentage of total sown area. Many Magozi irrigators who experienced partial or total land failure ended up losing money they had invested in early preparation tasks such as weeding, levelling, seeding, etc. Such monetary losses were defined as *investment losses* expressed in Tanzanian shillings per sown area (TZS/ha).

Interviewees were also asked to report on their potential paddy rice output and harvested area in a hypothetical situation where their production would not be water-limited. Thus, *potential area increase* and *potential yield* (Y_P) were defined. The difference between the potential and the actual yield reflects the *yield gap* (Y_G). The *yield gap to actual yield ratio* (Y_G-to-Y_A) was calculated as yield gap over actual yield (van Ittersum et al. 2013). Strictly speaking, the definition of yield gap accounts, not only for water restrictions, but also for limitations in, economic, knowledge and agronomic factors. However, the objective of this study is to assess the impact of water supply, hence irrigators were asked to report on their potential production without water limitations, whilst leaving all other factors unchanged.

Current global yield databases are mostly based on farmer-reported data, which inevitable entails biases and inaccuracies (FAO and DWFI 2015). Previous research in east Africa (Leach & Scoones 2015) detected that some farmers underestimated their yields in expectation of food aid from the research project, while others tended to overestimate yields with the intention of being viewed as ‘good farmers’ and thus receive preferential treatment from the project. Thus, reported yields should be evaluated by comparison against independently collected data and direct on-farm measurements and monitoring (FAO and DWFI 2015). Ideally, Y_P and Y_G should be estimated using simulation models based on high-quality data on weather, soil and crop management (Grassini et al. 2015). However, in many developing countries, weather and soil data are of low quality and too spatially scarce for estimating Y_P and Y_G at specific locations or in small geographic regions (*Ibid.*).

Frontier analyses in various locations across West and Central Africa (Neumann et al. 2010) estimate rice yield gaps of between three and seven tonnes per hectare. In a review of rice yield studies in Tanzania, Nhamo et al. (2014) note yield gains of 0.5-1.4 tn/ha between fields with and without treatment effects related to nutrient, soil and weed management. However, no comprehensive analysis on rice yield gap has been conducted in Tanzania (Sekiya et al. 2017).

The reported 2015 Y_A mean in Magozi is 1.8 tn/ha, which is considerably below the national irrigated rice average yield of 3 - 8tn/ha (SAGCOT 2012). However, Magozi yields are close to those observed within similar smallholder irrigation schemes in southern Tanzania, including the districts of Usangu (2.5 tn/ha) (Lankford 2004), Kilombero (1.1-1.2 tn/ha) and Kyela A (1.3-2.1 tb/ha) (Mwaseba et al. 2007). By comparing rice yields between water-abundant and water-stressed sections of traditional irrigation schemes in Tanzania, Lankford (2004) notes a difference of 1-1.5 tn/ha. This figure is in-line with the 1.0 tn/ha yield gap reported in by water-dissatisfied irrigators in Magozi.

4.4 Site description

The analyses in this chapter are based on the Kiwere and Magozi irrigation schemes in Tanzania (see Chapter 2 for further details). The data used originate from the 2015 fieldwork survey comprising 79 households in Kiwere and 76 in Magozi.

Among all agricultural activities, irrigated crops account for the largest portion of revenues and inequality within the Tanzanian schemes (Table 4-1). Net incomes could not be calculated as there are no data available on expenses broken down by agricultural activities (see Section 2.3).

Table 4-1 **Agricultural revenue and revenue inequality breakdown by activity (percent)**

	Kiwere		Magozi	
Agricultural activity	**Revenue**	**Revenue inequality**	**Revenue**	**Revenue inequality**
Irrigated crops	57	56	81	76
Dryland crops	26	26	5	9
Livestock	8	7	9	7
Milk and other	5	4	3	3
Labour	4	6	2	5
Total	100	100	100	100

Source: Author's calculations from 2014 baseline survey data

Without flow measuring devices, water-sharing rules in Kiwere and Magozi are defined on a time-basis. In Kiwere, plots at the tail-end of the main canal are scheduled to receive water in the mornings, while farms located closer to the intake should be supplied in the afternoons. Despite this rule, some upstream irrigators tend to divert water to their plots in the morning, thus restricting the flows downstream. In these situations, tail-enders have to walk along the head section of the main canal to find out which gates have been tampered with and by whom. When confronted, head-enders withdrawing water outside of their allocated schedule, typically make an apology and then close their gates. However, by the time the flows are restored and tail-enders go back to their plots, it is already the afternoon, and thus, no longer their turn to irrigate. In Magozi, the rules dictate that irrigators flood-irrigate their rice fields during a certain amount of time proportional to their plot size. This rule is very rarely followed given that rice growers have a strong incentive to over-irrigate in order to keep their fields flooded (Ostrom & Gardner 1993). Rice is very vulnerable to water deficit, yet highly tolerant to water excess, which also helps in keeping weeds under control.

Water management within the Kiwere and Magozi scheme is further undermined by the system's lack of operability. During fieldwork from May to July 2015, it was observed that most structures and canal sections were defective and unable to perform their basic functions (Table 4-2).

Table 4-2 **Number of infrastructure observations by type, functionality and maintenance levels**

		Kiwere		**Magozi**	
		Canal reaches	**Control structures**	**Canal reaches**	**Control structures**
Functionality	Defective	37	14	62	21
	Functional	14	0	39	8
	Total	*51*	*14*	*101*	*29*
Maintenance	Fair	12	5	25	9
	Good	3	1	17	7
	Poor	36	8	59	13
	Total	*51*	*14*	*101*	*29*

Source: Author's calculations from fieldwork

In Kiwere and Magozi, most of the control structures − gates and diversion boxes − were missing the original iron boards aimed at regulating water flows. During fieldwork, it was mentioned that some boards were removed as they started to malfunction due to lack of maintenance, while others mentioned that some boards had been stolen to be sold as scrap metal. In absence of proper opening/closing mechanisms, makeshift gates are made out of materials such as wooden boards, mud and sand bags (Figure **4-1**)

Figure 4-1 **Defective irrigation control structures at Kiwere and Magozi**

Kiwere – canal gate with missing iron board

Magozi – diversion structure (left) and canal gate (right) with missing iron boards

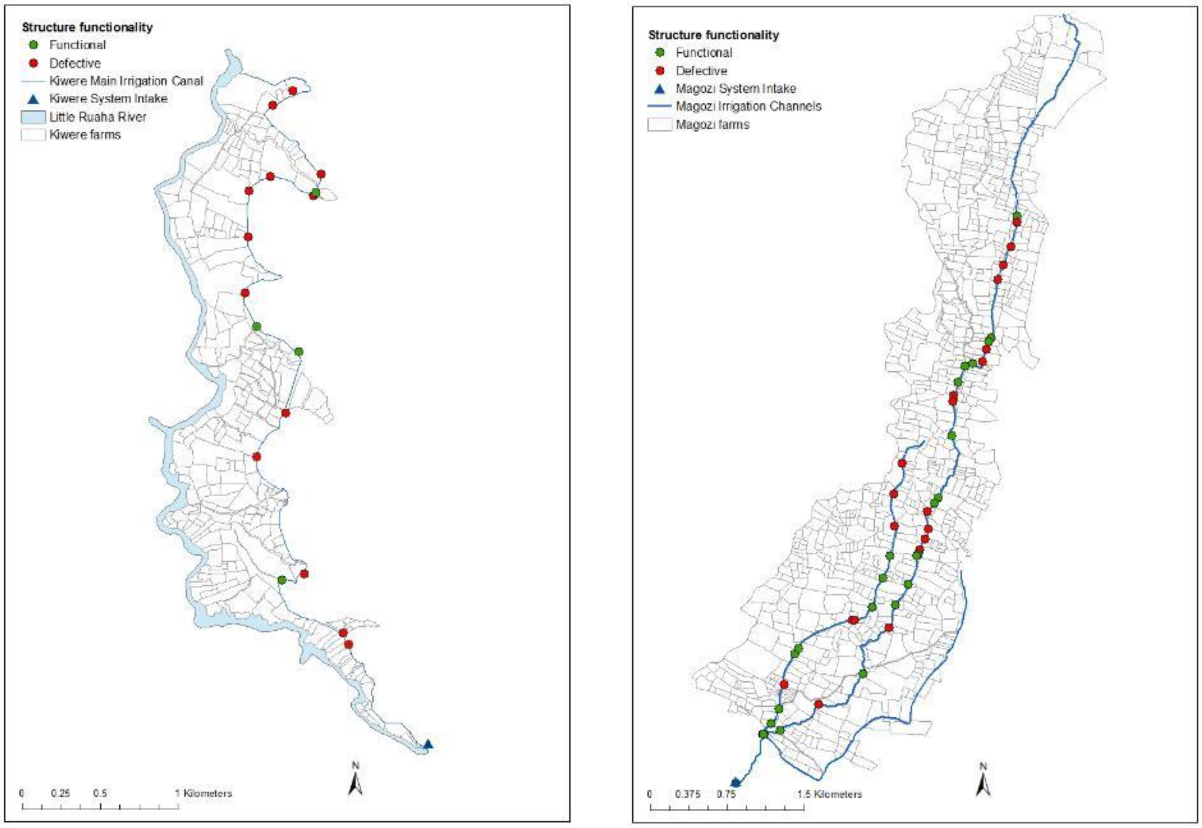
Kiwere – stone and sand bags used in replacement of missing iron gate

Magozi – use of sand bags in an attempt to control flows into distributary canals

Source: Author's own photos from fieldwork

As a result of maintenance issues, only a few control structures remain functional in both the Kiwere and Magozi schemes (Figure 4-2).

Figure 4-2 **Spatial representation of functionality of irrigation control structures**



Kiwere Magozi

Source: Author's own maps elaborated with ArcMap using fieldwork data

Poor maintenance along the earthen canals has resulted in eroded side-slopes and overgrown native vegetation, which considerably increased seepage losses. Within the middle section of the Magozi scheme and at the tail in Kiwere, several canal banks are collapsed, thus causing constant flooding of the surrounding areas (Figure 4-3). From the infrastructure observations it is apparent that both schemes suffer from very high levels of transmission losses. Inevitably, such losses aggravate water scarcity within the schemes, especially at the tail-end where flows are lower and infrastructure is generally in worse conditions. Most of the canal reaches that remain functional are stone or concrete lined, which require less maintenance and are less susceptible of deteriorating due to erosion, vegetation growth, etc.

Figure 4-3 **Defective earthen canals in Kiwere and Magozi**

Kiwere flooded field due to overflow from main canal

Magozi – flooded paddy filed due to complete collapse of the canal banks

Kiwere

Magozi

Defective earthen canals (no integrity of side slopes) with poor maintenance (excessive vegetation overgrowth)

Source: Author's own photos from fieldwork

4.5 Results

This section is structured into three parts. The first examines irrigators' perceptions on the importance and reasons for inequities in water supply. Next, qualitative responses are analysed to determine how greater equity of water supply could help mitigate economic disparities. Finally, tests for statistical significance are conducted to investigate how yields and other measures of agricultural production vary depending on water supply.

4.5.1 The reasons behind inequity of water supply

The most common reason attributed to inequity of water supply was water scarcity, which was mentioned by almost a quarter of interviewees across both schemes (Table 4-3). One irrigator from the rice-growing Magozi scheme mentioned that:

> 'Water is so scarce that even your mother, your brother, will block the water to you! ' (male irrigator, age 54, Magozi)

Breakage of rules was the second most common explanation, although this was not understood as a generalised problem, but rather a result of the 'occasional selfish behaviour of a few irrigators'. Two irrigators pointed out that:

> 'The ones who break the rules earn enough money to pay the fines, so they don't care' (female irrigator, age 52, Magozi)

> 'The poor break the rules out of frustration and desperation. The rich break the rules out of greed' (male irrigator, age 45, Magozi)

The third most commonly perceived factor for uneven supply was weak leadership of the IOs - often linked to bribery and conflict of interest. One irrigator in Kiwere expressed his discontentment saying that:

> 'Even the chairperson [of the IO] broke the rules and never paid the fine. He claimed that, as a chairperson, he had immunity to the rules' (male irrigator, age 24, Kiwere)

Finally, some irrigators blamed water distribution issues on the lack of understating of water-sharing rules, while another small group listed a range of other causes, such as malfunctioning infrastructure and personal reasons. One elderly irrigator at the head-end of the Kiwere scheme explained that:

> 'My turn to irrigate is in the afternoon, but it gets too hot for me to work in the field' (male irrigator, age 22, Kiwere)

In order to get a better understanding of the issues surrounding water distribution, in-depth interviews were held with key members (secretaries) of the IOs management boards. In both schemes, leaders agreed that water-sharing rules are not always respected, which they believe is a result of ineffective deterrence and prosecution mechanisms.

Deterrence is based on the application of monetary fines set by the IOs, yet significant income disparities among irrigators mean that, unlike poorer irrigators, wealthier individuals can easily pay for the penalties. In the Magozi scheme, breakage of rules is punished, on a case-by-case basis, with sanctions varying from 50,000 to 300,000 TZS (circa 23-138 USD). To put this into perspective, such fines only represent a minimal portion (one to four percent) of the mean household annual revenue of the top quintile, yet they pose a much greater burden on poorer irrigators, taking up to 10 - 61 percent of the average yearly earnings of families in the bottom quintile. Irrigators who repetitively break the rules or fail to pay the fines can be taken to court. However, the nearest court is located in the regional capital of Iringa, which lies 20 km away from Kiwere and 50 km from Magozi. The need to attend several court hearings and the deficient public transport system become major impediments for poor-resourced irrigators to pursue legal action.

The secretary of the Magozi IO noted that poor levels of infrastructure repair and maintenance (leading to significant water losses), were partially due to inadequate budgeting by the IO. It was explained that, under the current system, all fees and fines paid by irrigators contribute to a general budget, which serves to cover a range of aspects. Typically, mid and long-term requirements, including repairs and maintenance, are set aside to prioritise more immediate needs, such as interest repayment.

Table 4-3 **Irrigators' perceptions of the reasons for inequity of water supply**

In your own opinion, why is water not equitably distributed within the irrigation scheme?	**% Responses**		
	Kiwere (n=79)	Magozi (n=76)	Combined (n=155)
Water scarcity	18	29	23
Individuals breaking rules	25	16	21
Weak leadership	9	16	12
Lack of understanding of rules	14	7	10
Other	10	9	10
Don't know/Don't perceive inequality	24	24	24

4.5.2 How can equity of water supply mitigate economic inequalities

There is a widespread perception of inequality among Kiwere and Magozi irrigators. Over two-thirds of interviewees think water is not equitably distributed (Table 4-4), while 90 percent agree that significant economic inequalities exist within their communities. Interestingly, four-in-five irrigators believe the economic gap could be mitigated through the provision of more equitable water supply, chiefly in Magozi. As one irrigator explained:

> 'The only way of removing the wealth gap is by improving water supply. Then, motivation and hard work will be the sole limiting factors' (male irrigator, age 42, Magozi)

The critical impact of water on irrigators' welfare was highlighted by a Magozi irrigator who is a single mother:

> 'This year, I have harvested no rice at all and now I am even poorer. This is because I didn't have enough water. People talk about improving many things, but for me water comes first. If I don't have water, I have nothing' (female irrigator, 28, Magozi)

Table 4-4 **Irrigators' responses to specific questions on water and inequality**

Question	Answer	% Responses Kiwere (n=79)	% Responses Magozi (n=76)	% Responses Combined (n=155)
Do you think water is equitably distributed within your irrigation scheme?	Yes	23	16	19
	No	70	68	69
	Neutral/Don't know	7	16	12
Do you think there is a significant economic gap among the members of the irrigation scheme?	Yes	89	91	90
	No	11	9	10
	Neutral/Don't know	-	-	-
Do you think more equitable water supply can help reduce the economic gap?	Yes	74	92	83
	No	25	4	15
	Neutral/Don't know	1	4	2

During the interview process, irrigators who agreed that water equity could help reduce the economic gap were asked to elaborate on the possible linking mechanisms. The articulate responses provided by interviewees were synthesised into seven main common themes (see 4.3.1), as shown in Table 4-5. The most frequent explanation is rooted in the belief that lack of adequate water supply is one of the main reason why disadvantaged irrigators remain trapped in poverty. Respondents argued that irrigators who suffer from insufficient and/or unreliable water supply cannot reach their full crop production potential. By contrast, water-abundant farmers do not experience such restrictions. Two interviewees explained that:

> 'Poor irrigators are the ones who don't have water' (male irrigator, age 60, Magozi)

> 'If poor irrigators had better water supply, they could improve their production. Then, they would have more time and resources to invest in other businesses' (female irrigator, age 38, Magozi)

The second most common argument was that equitable water distribution would improve irrigators' working conditions by reducing risk and conflict; enabling planting and harvest at the right time; and stabilising crop production and food prices. Currently, the delay in the optimal irrigation schedule results in low quality crops (water supply doesn't meet crop needs through its life cycle) and late harvest (when there is already an oversupply of the particular product in the market). The combination of these two factors means that rice that is inadequately irrigated can only be sold at a low market price. A more even water supply would mean that small irrigators could harvest at the same time and thus, benefit from stronger bargaining power when marketing their produce.   One irrigator summarised:

> 'If water is equitably distributed, we can all plant and harvest at the right time. Then, we would be able to market together and obtain better prices' (male irrigator, age 54, Kiwere)

In Kiwere, 65 percent of the interviewees reported that a lack of sufficient water supply during the day forces them to work in the evening and night. During this time, there is less competition because many irrigators have gone home and there is more water left in the canals. However, it hampers their productivity given the extra difficulty of cultivating with little or no daylight. It also poses a security issue, especially for female irrigators, who fear they become an easy target for violent attacks and robberies and, hence, they choose not work in the fields at dark.

Two-thirds of respondents in Kiwere noted they experience regular or occasional conflict with upstream, downstream and/or neighbouring irrigators. Reportedly, conflict greatly disrupts their working life, as they end up spending significant amounts of time and energy being vigilant and arguing over water, instead of concentrating their efforts on cultivation and other non-farming activities. Such finding mirrors previous studies in domestic water access (Jemmali & Abu-Ghunmi 2016; Sullivan 2002) that highlight significant opportunity costs (time and efforts) used to search for water. It is noteworthy that, both for irrigation and domestic uses, females tend to carry greater risks and burdens when trying to access water, compared to their male counterparts.

Also, water-related quarrels deteriorate social relationships in such a way that disadvantaged irrigators become excluded from cooperative initiatives such as collective marketing, training opportunities or access to finance. Conflict and social exclusion are also relevant for food security in the Magozi scheme where, besides irrigated rice, only a very limited variety of dryland crops are grown. Being relatively remote from the main regional town and other irrigation districts, villagers in Magozi rely on collective purchasing and transportation to access fruits and horticultural produce from outside their area.

Increasing crop production, either through expansion of the irrigated area or higher crop yields, was also frequently stated as a factor that could help narrow the economic gap. For example, one rice-grower from Magozi indicated that insufficient water supply results in increased soil salinity, which greatly affects the quality and yield of his crop. Higher certainty of timing and volumes was also perceived as a critical factor, as it would allow irrigators to better plan their activities. Currently, uncertainty of water supply means that irrigators take a significant risk investing in land preparation at the start of the season, without knowing whether they will receive the water they require. As one irrigator said:

> ‘When farmers see they have no water, it breaks their heart because of all the money and effort they have invested. Then, they give up farming or go to dryland’ (female irrigator, age 54, Kiwere)

Furthermore, one-in-eight sampled irrigators in Magozi believed that a more equitable distribution would give the poor the ability to irrigate their own land. As a result of water scarcity and subsequent crop failure, irrigators often have to abandon their own plots. Instead, they find themselves in precarious conditions renting land or working as labourers in water-abundant parts of the scheme. Most of them feel considerably underpaid, yet with no other skills and a weak bargaining positon, this often becomes their only source of livelihoods. During the interviews, it was mentioned that ‘more equitable water supply will break the dependency of poor farmers on rich ones through labour’. It was explained that:

> ‘At the start of the irrigation season, some farmers are not receiving enough water, so they have to labour for richer ones. Then, later in the season, the optimal time for cultivating has been missed. This means poor farmers cannot become self-sufficient because they depend on water supply’ (female irrigator, age not available, Magozi)

Also, without being able to access formal financial institutions, struggling irrigators turn themselves to better-off ones for small loans. On the one hand, interviewees indicated they are generally grateful to borrow money from fellow irrigators. On the other hand, they believe they are being taken advantage of through extremely high interest rates. In Magozi, borrowers would typically have to repay twice the amount borrow over the course of one irrigation season (circa six months).

Table 4-5 **Irrigators perceptions of the linkages between water and economic inequalities**

How do you think better water supply could help reduce the economic gap?	**% Responses**		
	Kiwere (n=79)	**Magozi (n=76)**	**Combined (n=155)**
Opportunity for poor irrigators to increase production	19	16	17
Improved farming conditions	18	12	15
Opportunity to expand irrigated area	6	21	14
Increased yields	13	11	12
Higher certainty of supply	10	7	8
Ability to irrigate own land	-	13	6
Other	8	14	11
Water won’t help reduce the economic gap	27	8	17

4.5.3 Yield and yield gap analysis in Magozi

In the previous section, qualitative methods are used to investigate possible linkages between perceptions water supply and economic inequalities. In this section, the aim is to test such associations using statistical analyses. Most of the linkages identified (Table 4-6) relate to irrigation practices for which quantitative data from the 2015 survey is available. Therefore, a series of quantitative measures of agricultural production are defined (see Table 4-6 and Section 4.3.2) mirroring the associations between water and economic inequality noted in Section 4.5.2. The next chapter, expands on the qualitative analyses by developing multiple regression models to investigate the association between income and yields with a series of natural, physical, human, social, financial and farm management factors.

Table 4-6 **Qualitative and quantitative links between water and economic inequalities**

Qualitative answers	**Quantitative measures**
Benefit the poor the most	Rice yields
Improved farming conditions	Investment losses
Higher certainty of supply	Failed land
Opportunity to expand irrigated area Ability to irrigate own land	Potential area increase
Increased yields	Yield gap Y_G-to-Y_A ratio

For statistical analyses, irrigators were classified into three sub-groups according to their level of water supply satisfaction (*satisfied*, *neutral* and *dissatisfied*). The summary statistics (Table 4-7) show that the percentage of failed land considerably decreases with irrigators' level of water supply satisfaction. On average, almost half of the land sown by *dissatisfied* irrigators could not be harvested, while the failed land among *satisfied* irrigators was only five percent of total sown area. Also, investment losses suffered by *dissatisfied* irrigators were, on average, 50 percent greater than those of *satisfied* irrigators and almost four times larger compared to *neutral*. Water-dissatisfied irrigators obtain 30 percent lower mean yields compared to their *satisfied* counterparts. They also suffer from greater yield gaps, both in absolute (kg/ha) and relative (Y_G-to-Y_A) terms.

On average, *dissatisfied* irrigators achieve yields that are only half of their potential, whereas *satisfied* growers exceed 80 percent. This means that, with an adequate water supply, currently *dissatisfied* irrigators would be the greatest beneficiaries as they could potentially double their yields, compared to a much lower increase (22 percent) by *satisfied* irrigators. Similarly, a more abundant and reliable water supply would enable *dissatisfied* irrigators to expand their harvested area 1.6-fold, whereas the possible extension for *satisfied* famers would be much lower. Thus, combining higher yields and greater harvested area, an improved water supply could result in a 240 percent increase in total paddy production (kg) for *dissatisfied* irrigators.

Table 4-7 **Summary statistics of land and crop productivity**

Failed land (%)						
Water Satisfaction	**N**	**Mean**	**Median**	**Std. Dev**	**Min**	**Max**
Satisfied	11	5	0	18	0	60
Neutral	15	23	0	35	0	93
Dissatisfied	50	45	45	40	0	100
Investment losses ('000 TZS/ha)						
Water Satisfaction	**N**	**Mean**	**Median**	**Std. Dev**	**Min**	**Max**
Satisfied	11	195	0	593	0	1,977
Neutral	15	79	0	157	0	532
Dissatisfied	50	296	254	282	0	1,112
Actual yields (kg/ha)						
Water Satisfaction	**N**	**Mean**	**Median**	**Std. Dev**	**Min**	**Max**
Satisfied	11	2,487	2,348	479	1,606	3,274
Neutral	15	2,239	1,853	545	1,483	3,212
Dissatisfied	40*	1,751	1,016	690	371	3,048
Yield gap (kg/ha)						
Water Satisfaction	**N**	**Mean**	**Median**	**Std. Dev**	**Min**	**Max**
Satisfied	11	491	330	561	0	1,977
Neutral	15	859	834	714	0	2,780
Dissatisfied	50	983	968	805	0	3,336
Y_G-to-Y_A ratio						
Water Satisfaction	**N**	**Mean**	**Median**	**Std. Dev**	**Min**	**Max**
Satisfied	11	0.22	0.14	0.26	0.00	0.84
Neutral	15	0.45	0.35	0.46	0.00	1.80
Dissatisfied	40†	0.98	0.45	1.67	0.00	9.00
Potential area increase (ha)						
Water Satisfaction	**n**	**Mean**	**Median**	**Std. Dev**	**Min**	**Max**
Satisfied	11	0.32	0.00	0.88	0.00	2.95
Neutral	15	0.63	0.00	0.90	0.00	2.63
Dissatisfied	50	0.61	0.40	0.67	0.00	2.83
Relative potential area increase (%)						
Water Satisfaction	**n**	**Mean**	**Median**	**Std. Dev**	**Min**	**Max**
Satisfied	11	34	0	81	0	270
Neutral	15	148	0	337	0	1300
Dissatisfied	40†	161	0	293	0	1700

For the aim of comparison: 1 USD = 2,237 TZS at 07/06/2017 exchange rate

Note: † 10 irrigators reported harvested area equal to zero. In these cases, yields and percentages calculated relative to harvested area were mathematically undefined. Hence, the smaller sample size (n=40).

Statistical significance tests (Table 4-8) were conducted using the Kruskal-Wallis (Kruskal 1952) and the Dunn test (Dunn 1961). The Kruskal-Wallis test (the nonparametric equivalent of the one-way analysis of variance) indicates that the distributions of all measures differ significantly across groups. Subsequently, the Dunn test in the post-hoc analysis reveals which pairs of groups differ significantly from each other. All measures are significantly different between *satisfied* and *dissatisfied*. Conversely, the differences between *neutral* and the other two groups are only significant in four out of the seven cases.

Table 4-8 **Kruskal-Wallis and Dunn test results on irrigated agricultural production**

	Kruskal-Wallis χ^2	**Dunn's *z***		
		Dissatisfied / Satisfied	**Satisfied / Neutral**	**Neutral / Dissatisfied**
Unproductive land	12.27***	3.19***	1.14	2.07**
Investment losses	15.38***	3.03***	0.27	3.06***
Actual yields	17.54***	-3.68***	-1.07**	-2.72***
Yield gap	4.52	2.13**	1.45*	0.49
Y_G-to-Y_A ratio	5.76*	2.38***	1.35*	0.90
Potential area increase	7.03**	2.60***	1.41*	1.04
Relative potential area increase	7.42**	2.58***	1.09	1.47*

Note: The values are statistically significant at ***$p < 0.01$, **$p < 0.05$, *$p < 0.10$

4.6 Discussion

Economic inequality is a major issue hindering effective poverty reduction and inclusive growth, chiefly in developing areas. Within the context of irrigation, access to communal resources plays an important role in determining how the benefits from agriculture are distributed. Drawing from irrigators' perspectives, this chapter examines the association between irrigation water supply and economic inequalities within the Kiwere and Magozi schemes in Tanzania. Understanding irrigators' opinions is particularly important given that collective action is often motivated by perceptions, rather than the actual level of inequality (Kawakami & Dion 1995; Mine et al. 2013). Furthermore, sophisticated measures of water distribution commonly have limited application in low-technology, traditional systems, like the ones in this study. In fact, lack of metering instrumentation and impeded operability of control structures gravely hinder the acquisition of objective water supply data and the enforcement of water distribution rules.

Perceptions of Tanzanian smallholder irrigators on water supply and economic inequalities

The in-depth qualitative investigations in Kiwere and scheme indicate that, according to irrigators, inequities in water distribution are caused by a combination of technical, human and institutional factors. These findings are consistent with previous studies in Nepal, India and Pakistan pointing at various reason behind inequalities in irrigation water distribution, including scarcity (Lal Kalu et al. 1995); petty organisation rules, technical issues (Bhattarai et al. 2002); corruption, unaffordable legal costs (Rijsberman 2008); and ineffective means of enforcement and sanctioning (Starkloff 2001).

Irrigators widely agreed that significant water supply and economic inequalities exist within their communities. In addition, most of them affirmed that greater equity of water distribution could help reduce the wealth gap. Open-ended questions allowed interviewees to express their own views on the issue, which led to the identification of important linkages between water and wealth, some of which had not been previously noted in the literature. While previous literature (Bhattarai et al. 2002; Chambers 1988; Sharma et al. 2008) focuses on yields and incomes, qualitative results of this research, described below, highlight the effect of water supply inequity on human and social capital.

First, unreliable water supply makes it almost impossible for many irrigators to follow a regular irrigation schedule, either daily or seasonally. As a result, affected irrigators spend most of their time and efforts on irrigation, which is to the detriment of potential diversification into other non-agricultural, more profitable activities. This is particularly important because, as shown in Section 3.7.2, households with diversified sources of livelihoods tend to earn significantly higher incomes than those relying solely on agriculture. Second, inadequate timing of water supply for paddy irrigation results in late harvest and poor grain quality, thus dramatically reducing the crop's marketing potential along the value chain (Nkuba et al. 2016). Third, uneven water distribution becomes a major source of conflict that deteriorates relationships between disadvantaged and powerful famers. Dissatisfied irrigators can be viewed as troublesome and thus, become marginalised from communal initiatives, such as decision-making, training, financial services, crop marketing, bargaining input prices, etc. While some benefit from pooled marketing, exclusion from such economies of scale translates into greater costs and lower earnings for the disadvantaged, thus feeding back into a widening economic gap. Another important factor of social power that connects water and economic inequalities is the dependence of water-scarce irrigators on water-abundant for jobs, land rent and loans. Although in some cases these might be the only short-term livelihood strategies, water-disadvantaged irrigators stated the conditions imposed (e.g. low pay, high interest) were generally unfair.

With regards to enforcement of water-sharing rules, this chapter finds that deterrence and prosecution means are biased against the poor. The fines due to non-compliance of rules are based on the gravity of the offence, irrespective of offender's economic level. Hence, while poor irrigators are compelled to respect water-sharing rules, monetary fines provide much less incentive for wealthy irrigators. Likewise, ill-resourced irrigators are typically unable to access legal services or attend court hearings, which, in contrast, wealthy irrigators can better afford. Chapter 6 examines water and irrigation polices in Tanzania to identify current shortfalls in the legislative framework and to discuss possible interventions aimed at improving irrigation water distribution within traditional irrigation schemes.

The results of the statistical analyses revealed that paddy rice yields in the Magozi scheme increase with irrigators' level of water supply satisfaction. These figures are consistent with previous observations in Asia (Chambers 1988; Collins et al. 2014) in which head-end irrigators obtained greater rice yields than tail-end ones. Such parallelism suggests there could be an association between water supply satisfaction, location and yields.

Comparison of agricultural production measures across population sub-groups revealed that irrigators who are not satisfied with their water supply are affected in two ways. First, *dissatisfied* irrigators suffer from lower yields and greater yield gaps than their *satisfied* counterparts. Second, water-dissatisfied irrigators also suffer from greater levels of unharvested land and investment losses. Crop yields and yields gaps are a common measure of agricultural productivity. However, given that, by definition, yields are calculated over harvested area, they ignore the impact of land failure on crop production. Thus, in the study of water supply and crop production disparities, a better understating can be gained by analysing, not only yields, but also differences in unharvested areas.

For irrigators experiencing crop failure and investment losses, irrigation can push them further down into debt and poverty, rather than supporting their livelihoods. A more reliably water supply could potentially change this situation by lowering their risk of crop failure and securing their investments. Similarly, high yield gaps can be interpreted as a great potential for improvement. In fact, if water becomes more equitably distributed, *dissatisfied* irrigators would be the greatest beneficiaries in terms of yields and harvested areas. From this perspective, it can be argued that adequate water distribution may have an inequality reducing effect on crop production, and therefore, possibly on incomes as well.

Improving irrigation water distribution and increasing yields could, arguably, have beneficial environmental effects. While certain parts of the schemes do not receive enough water, other sections are systematically over-irrigated, leading to nutrient loss, rising water tables and excessive soil salinity (Francois & Maas 1999). Furthermore, greater yields may alleviate the pressure for expanding agriculture into new land, helping protect environmentally sensitive areas, such as forests (Conceição et al. 2016). This is particularly relevant for water-scarce irrigators who, as noted during the survey, may find themselves forced to abandon irrigation and move into dryland farming.

Disparities in water supply, economic levels and yields also have important implications for food security. First, as noted by Devereux (2016 p. 58), ‘food insecurity is often correlated with social exclusion and political marginalisation’, both of which are common consequences of water-related conflicts among irrigators. Moreover, communities with high levels of income inequality have also been found to suffer from greater levels of food insecurity (Kawakami & Dion 1995). Irrigators whose crop productivity is severely affected by inadequate water supply may become more prone to food insecurity because of lower revenues from their agricultural sales, and also due to insufficient crop production for self-consumption.

In summary, equitable access to irrigation water supply is critical for rural livelihoods, as it holds the potential to impact economic inequalities in a number of ways, leading to either a positive or negative change. Such inequality interconnections are important, not only from a crop productivity standpoint, but also to build fairer and mutually beneficial relationships among irrigators. In addition, more equitable water distribution could also help to alleviate poverty, protect the environment and enhance food security. Importantly, irrigation development strategies should take into account the linkages between water supply and economic disparities, in order to promote equitable distribution of agricultural benefits and maximize social justice.

Beyond Tanzania, such considerations may also be relevant in other developing areas, such as South America, South Asia and the rest of SSA, which share similar challenges in terms of growing economic inequalities and the need to improve rural welfare.

4.7 Conclusions

This chapter investigates water supply and economic inequalities within the Kiwere and Magozi irrigation schemes in Tanzania, using data on 155 households from the 2015 survey. A mixed methods approach is used to investigate: a) the reasons causing inequity of water supply; b) the mechanisms linking water and economic inequalities; c) variances in agricultural production based on water supply.

The survey results identify four main reasons for inequity of water supply: water scarcity; individuals breaking rules; weak leadership and lack of understanding of rules. In-depth interviews with key members of the IOs management boards also reveal that current deterrence and prosecution practices are ineffective, chiefly due to inadequate fine systems and constrains in accessing the regional court.

According to interviewees, there are several mechanisms whereby more equitable water distribution could help narrow the economic divide within their communities. These include providing a greater opportunity for the poor; improving farming conditions; expanding irrigated areas; increasing yields; providing higher certainty of water supply; and improving their ability to irrigate their own land. Tests for statistical significance indicate that irrigators who are dissatisfied with their water supply have significantly more unproductive land, higher investment losses, lower yields and greater yield gaps compared to those who are satisfied or neutral.

The qualitative and quantitative results of this study are consistent in showing that water distribution within the two irrigation schemes seems to be biased against the most disadvantaged irrigators. Moreover, inequitable distribution of water may aggravate existing economic inequalities within the community. Based on yield gap analysis, the findings indicate that water-dissatisfied irrigators obtain lower yields, but they hold the largest potential for increased production if water was not a limiting factor.

Chapter 5 The effect of water supply on incomes and yields: a quantitative assessment

5.1 Chapter objectives

The previous chapter has highlighted the important linkages between water distribution and economic inequalities, as perceived by irrigators in the Magozi and Kiwere schemes. Building on this insight, the aim of this chapter is to further quantitatively investigate the association between water supply and agricultural incomes using regression modelling. Using both qualitative and quantitative techniques will allow greater insights into findings and help us to more comprehensively explore a range of issues.

5.2 Introduction

It is widely understood that gravity-fed, low technology irrigation systems present considerable differences in water distribution between head and tail-ends (Hussain & Hanjra 2003; Maskey et al. 1994; Ostrom & Gardner 1993; Senaratna Sellamuttu et al. 2014). Typically, farms located closer to the system's intake are able to withdraw larger volumes of water with greater frequency and reliability compared to those further downstream. Given that adequate water supply (volumes, reliably, timing, etc.) is crucial for successful cultivation of irrigated crops, this suggests that irrigators who are water-underprovided are less productive than their water-advantaged counterparts (Ostrom 1993). Thus, if water affects irrigated crop production and crop production generates revenues, then water supply may impact incomes from irrigated agriculture (Bhattarai et al. 2002). Subsequently, from an inequality perspective, asymmetries in water distribution could potentially widen the income gap between irrigation community members.

While the theoretical connection between water, location and incomes is consistent with the experiences reported by Kiwere and Magozi irrigators (see Chapter 4), an important question to ask is whether such association is also reflected by quantitative measures of crop production and farm income. This chapter formulates a set of hypotheses arguing that adequacy of water supply and proximity to the system's intake are positively associated with irrigation incomes and crop yields and seeks to model it quantitatively with various regression models.

5.2.1 A Tanzanian national perspective

Out of all agricultural activities in Tanzania, cropping is the largest contributor to national GDP, accounting for 71 percent of the sector share (Table 5-1)

Table 5-1 **Decomposition of Tanzania's GDP in 2012**

Sector	GDP share (%)	
Services	47.6	
Industry and construction	24.0	
Agriculture	28.4	
Crops		20.2
Livestock		4.3
Forestry and hunting		2.4
Fishing		1.6

Source: The United Republic of Tanzania (2013b)

In mainland Tanzania, cereals are the number one crop in terms of area planted area and total output (Table 5-2) (The United Republic of Tanzania 2013b). Maize accounts for 70 percent of the total area planted in cereal, while paddy rice comes second accounting for one-sixth of the cereal area.

Table 5-2 **Annual crop production and planted area in Tanzania in 2007/08**

	Crop production		Planted area		
	'000 tonnes	Percentage of total	'000 ha	Percentage of total	
Cereals	7,593	72	5,797	69	
Maize					48
Paddy rice					11
Sorghum					7
Other					3
Roots and pulses	1,688	16	894	11	
Oil crops	548	5	766	9	
Vegetables	757	7	905	11	
Total	10,585		8,362		

Source: The United Republic of Tanzania (2013b).

Agricultural land is in Tanzania is estimated at 42 percent of the total area, divided into grassland (25 percent) and cultivation (17 percent) (FAO 2016). Dryland accounts for 98 percent of the land under cultivation, whereas only a small area is equipped for irrigation, predominantly, under traditional systems (Table 5-3). Irrigation in Tanzania has experienced significant growth, with irrigation users rising from 33,000 in 2005 to one million in 2012 (The World Bank 2013).

Between 2002 and 2013, the irrigated area doubled from 184,330 ha to 363,514 ha, and it is estimated that it could be expanded up to 2.1 million hectares across four high-potential regions, including Iringa (FAO 2016). Large-scale schemes controlled by the government or external agencies only account for 15 percent of Tanzania's irrigated area. Conversely, the remaining 85 percent is under traditional irrigation schemes, directly managed by smallholder farmers. Two-thirds of the area under traditional irrigation schemes is equipped with improved infrastructure as a result of external intervention (e.g. government or donor agencies). These schemes – as it is the case of Kiwere and Magozi − are referred to improved traditional irrigation schemes.

Table 5-3 **Land use in Tanzania in 2013**

	Area ('000 ha)	Percentage of total
Non-agricultural land	55,080	58.14
Meadows and pastures	24,000	25.34
Dryland Agriculture	15,286	16.14
Traditional irrigation without external intervention	117	0.12
Improved traditional irrigation	191	0.20
Large-scale irrigation	55	0.06
Total Area	94,730	

Source: Author's calculations from FAO (2016).

5.2.2 The case of Kiwere and Magozi schemes

Households in Kiwere and Magozi obtain incomes from various agricultural and non-agricultural activities, with irrigation representing the single largest source of livelihoods (Table 5-4).

Table 5-4 **Percentage of total household revenue by activity in 2013/2014**

	Kiwere	Magozi
Irrigated crops	48	67
Dryland crops and livestock	32	22
Off-farm activities	20	11

Source: Author's calculations from 2014 baseline survey

In Kiwere, tomatoes, maize and onions are the predominant crops, while Magozi is mainly dedicated to rice (Table 5-5). Kiwere receives its water supply from the Little Ruaha River all year round. The scheme is located 20 km north-west of Iringa − the regional capital – along an easily-accessible, gravel road. The continuous water supply and proximity to markets allow irrigators in Kiwere to cultivate a variety of horticultural crops that are harvested and sold throughout the year. This type of cash crops are not only important for the livelihoods of Kiwere growers, but in fact have become increasingly important for local and regional markets throughout Tanzania over the past decade (Lecoutere 2011).

Magozi lies 50 km away from Iringa, along the same road as Kiwere, although it is much more difficult to access (chiefly during the rainy season) given the steepness and poor quality of the road over the last 20 km. The Magozi scheme is located along the Little Ruaha River, upstream from Kiwere, and has a water withdrawal license only for the rainy season, i.e. December to May. Without easy access to markets and seasonal water provision, rice is a preferred choice in Magozi, as it needs little inputs and is only harvested once a year. Rice is increasingly becoming a valuable cash crop in Tanzania, following a shift in consumers' preferences and sharp rise in local demand (Mghase et al. 2010). While Asian imports partially fill the supply-demand gap in Tanzania and other sub-Saharan African countries, there is a strategic interest to increase domestic rice production (Seck et al. 2010; Therkildsen 2011). Rice yields in the Magozi scheme are comparable to those at the national level (Table 5-6), although there appears to be high inter-annual variability.

Table 5-5 **Annual crop production and area planted in Kiwere and Magozi in 2014**

	Kiwere		**Magozi**	
	Production (tonnes)	**Area (ha)**	**Production (tonnes)**	**Area (ha)**
Rice	8.0	4.5	390.9	101.4
Tomatoes	614.4	28.8	0.0	0.0
Maize	62.0	93.6	59.3	31.5
Sorghum	0.0	0.0	18.0	7.0
Onion	62.0	6.9	0.0	0.0
Other vegetables	34.9	12.4	0.0	0.0
Total	781.2	146.2	468.2	139.8

Source: Author's calculations based on 2014 survey data on 200 sampled households.

Table 5-6 **Paddy rice yields in Magozi and in Tanzania**

	Mean rice yield (tonnes/ha)
Magozi 2014	3.7
Magozi 2015	2.0
Tanzania irrigated rice	3.8
Tanzania rain fed lowlands	3.5
Tanzania rain fed uplands	1.2

Source: Author's calculations based on all data available for Magozi in 2014 and 2015 and Barreiro-Hurle (2012), Mghase et al. (2010) for Tanzania.

5.3 Literature review on crop yield and farm incomes

5.3.1 Theoretical and empirical links between water, location, yields and incomes

Inequity of irrigation water supply and its consequences have been widely explored in the agricultural economics and rural development literature. Most empirical and theoretical studies on gravity-fed, low technology irrigation systems find agreement on two main outcomes. First, water is inequitably distributed between head and tail sections and within distributary canals, with farms located further away from the water sources being the most disadvantaged. Second, such water asymmetries translate into other types of inequality including crop yields, incomes, wealth, cooperation and infrastructure maintenance.

In an extended review of empirical investigations across South and South-East Asia, Hussain (2005) concludes that productivity and wealth are most often unevenly distributed between canal reaches. Anwar and Ul Haq (2013) provides evidence of considerable disparities in water depths thorough calculations of Gini and Theil indices within the Hakra Branch Canal (*warabandi* system in Punjab, Pakistan). Using empirical data from *warabandi* irrigation systems in India and Pakistan, Sharma and Oad (1990) and Khepar et al. (2000) show that tail-enders received less water than head enders due to seepage losses. In addition to head vs. tail end contrasts, Maskey et al. (1994) note significant differences between upper and lower sections of canal reaches (i.e. within branch and distributary canals) regarding frequency of water supply and wheat yields in Nepali irrigation schemes. Similarly, following a detailed examination of water supply in a south Indian irrigation scheme, Mollinga (2003) concludes that important differences exist along distributary canals and that rotation scheduling helps to transfer water towards downstream areas.

Lipton et al. (2003) provide a framework for the analysis of irrigation and poverty in developing areas. Their approach considers that irrigation may affect the poor differently depending on their position along the distribution system and access to water. Drawing from experience in India and Pakistan, Bhattarai et al. (2002 p. 19) strongly argue that inequitable water distribution between head, middle and tail reaches of large scale irrigation systems ‘is one of the major factors contributing to income inequality in irrigated agriculture’. The authors provide an explanation of the theoretical reasons, citing disparities in crop yield, crop selection, water volumes, reliability of supply, infrastructure, water quality, inter-personal conflict, governmental services, incomes and wealth accumulation. A recent study in the island of Palawan, in the Philippines (Shively & Yao 2015) examines the impact of irrigation development on poverty and income inequality. The study concludes that irrigation has an ambiguous impact across various sections of the study area and that other financial (availably of off-farm work) and natural (cropping conditions) factors are major factors impacting poverty and inequality.

Bardhan and Dayton-Johnson (2002) propose that the intrinsic head-end location advantage will, in the long run, capitalise into higher land value, thus constituting another form of wealth inequality. Crop underproduction by tail-enders and yield inequality have also been noted as consequences of disparities in irrigation water access (Ostrom 1993). Ostrom (1993) and Lam (1996) argue that water asymmetries are caused by improper overuse by head-end irrigators, thus resulting in tail-enders not having predictable and adequate water flow.

5.3.2 Review of variable selection in regression analyses

The linkages between water access, yields, incomes and location have also been widely studied using regression-modelling techniques (Table 5-7). The choice of model (e.g. linear, spatial, probit, quantile, etc.) and variables commonly depends on the authors' research goals and available data. In studies of continuous variables, such as crop yields and incomes, Ordinary Least Squares (OLS) multiple linear regression model is one of the most common models, as highlighted in Table 5-7. The selection of independent variables is typically made by hypothesising which factors are expected to influence the dependent variable, drawing from existing literature and knowledge of the local context.

Table 5-7 **Literature summary on regression analyses on yields and incomes**

Source and country	**Dependent variable**	**Independent variables and model methodology**
Reardon et al. (1992) Burkina Faso	Net household income	Share of non-cropping income, asset vector (livestock, land, foodstock, savings, out-migration, cultivated cotton land), household size, household structure, prices (non-food, food), dummy near main road OLS Multiple linear regression
Battese and Coelli (1992) India	Value of rice output	Total irrigated land, total dryland, human labour, bullock labour, input costs Stochastic frontier production function

Table 5-7 **Literature summary on regression analyses on yields and incomes**

Source and country	**Dependent variable**	**Independent variables and model methodology**
Ostrom and Gardner (1993) Nepal	Water availability difference	Length of canal, labour input, headworks dummy, lining dummy, Terai (marsh, grassland, and savannah) dummy, farmer managed dummy Regression type not specified
Makombe and Sampath (1998) Zimbabwe	Maize yield	Area, fertiliser, water, water*fertiliser, labour/human capital OLS Multiple linear regression
Becker and Johnson (1999) Cote D'Ivoire	Rice yield; Weed mass; fertiliser efficiency	Water control dummy, seeding method, seeding density, age of transplants, herbicide, time of weeding, nitrogen rate, nitrogen timing, phosphorous application dummy OLS Multiple regression
Canagarajah et al. (2001) Ghana	Non-farm income	Female head of household, female, age, age squared, dependency ratio, attended primary school, attended high school, Central region, Eastern region, Western region OLS Multiple linear regression
Sadras and Bongiovanni (2004) Argentina	Maize yield	Nitrogen, area, season, yield inequality Correlation analyses
Wan (2004) China	Per capita disposable income	Household size, the dependency ratio, per capita capital input, average level of education of household members, per capita possession of cultivable land, and proportion of labour force employed in rural industrial enterprises. Multiple linear regression
Hussain et al. (2004) India and Pakistan	Wheat yield	dummy for middle location of farmers on the distributary, dummy for tail location on the distributary, dummy for improved varieties, sowing week, quantity of fertilisers, quantity of irrigation water applied measured at field outlet, total number of irrigations, time gap between pre-sowing and post-sowing irrigation, percentage of groundwater times electrical conductivity, dummy for season Multiple linear regression
Pasaribu and Routray (2005) Indonesia	Paddy production	Plot size, seed use per area, labour expenditure per area, fertiliser use per area, pesticide use per area, irrigation intensity, age of head, education level, frequency of canal maintenance OLS Multiple linear regression
Safa (2005) Yemen	Farm income	Family size; age of respondent, land size, number of animals, education, coffee production, agroforestry dummy Multiple linear regression (OLS and weighted least squares)
Bhatta et al. (2006) Nepal	Satisfaction with irrigation management	Age, education, land, distance from main canal, leakage, equity distribution Logit regression
Kato et al. (2006) Japan	Rice Yield	Water regime: flooded lowland, rainfed upland, irrigated upland, water deficit upland Correlation analysis

Table 5-7 **Literature summary on regression analyses on yields and incomes**

Source and country	**Dependent variable**	**Independent variables and model methodology**
Tittonell et al. (2007) Kenya	Maize yield	Soil type, fertility rating, area, slope, percentage of clay and silt, soil organic carbon, total soil nitrogen, delay in planting, plant density, diammonium phosphate, calcium ammonium nitrate, compost, residue, labour Multiple linear regression
Tittonell et al. (2008) Kenya	Maize yield	General (site, wealth ranking, fertility ranking); management (distance between homestead and sampling point), plant population density, weed level, striga level, nutrient intensity score); soil and landscape (soil wet chemistry, slope, soil spectral data) Classification and regression tree
Zhang et al. (2010) Iowa, USA	Corn yield	Vegetation index, precipitation, temperature, water holding capacity OLS Multiple linear regression and Spatial Lag
Kurukulasuriya et al. (2011) 11 African countries	Irrigation choice and net revenue	Temp winter, temp spring, temp summer, temp fall, precip winter, precip spring, precip summer, precip fall, plot area , log(household size), electricity, eutric gleysols, chromic vertisols, orthic luvisols, chromic luvisols, dystric nitosols, inverse mills ratio; flow winter, flow spring, flow summer Probit and multiple linear regression (OLS and corrected)
Auffhammer et al. (2012) India	ln(Rice yield)	Weather (rainfall, drought dummy, extreme rainfall, minimum temperature, solar radiation); non-weather (area, area with high yield varieties, fertiliser, labour) Multiple linear regression
Sarker et al. (2012) Bangladesh	Rice yield	Maximum temperature, minimum temperature, total rainfall OLS Multiple linear regression and Quantile Regression
Barnwal and Kotani (2013) India	Rice yield	Year, area, irrigation (% sown area), fertiliser, drought (dummy), rain intensity, temperature, precipitation, temperature standard deviation, precipitation standard deviation, agroclimatic zone, temp× agroclimatic zone, precipitation× agroclimatic zone Quantile regression
Ahmed et al. (2014) Nigeria	Rice yield	ln(fertiliser, pesticide, herbicide, labour, education, other area), dummy(irrigation used, land hired, seed source, age, other job, farmers organisation, training, rice major crop, livestock, flooding) OLS Multiple log-log regression (Cobb-Douglas production function)
Collins et al. (2014) Cambodia	Rice yield	Distance to water source Correlation analysis
Wang et al. (2015) Pakistan	Crop income per capita	Tubwell owner, tubwell water buyer, household size, age, education, labour, caste, water salinity, land fragmentation, soil quality, soil salinity, land holding
Koirala et al. (2016) Philippines	Rice yield	Area, output value, seed cost, fuel cost, fertiliser, labour, capital, irrigation cost, male age, male education, female age, female education, household size Stochastic production frontier models

Table 5-7 **Literature summary on regression analyses on yields and incomes**

Source and country	**Dependent variable**	**Independent variables and model methodology**
Hirooka et al. (2016) Cambodia	Leaf area index	Seeding date, planting method, water score, carbon in soil, carbon/nitrogen ratio in soil, nitrogen fertiliser (excluded weed due to inadequate data) Analysis of Covariance
Silva et al. (2017) Philippines	Rice yield	Cultivated land, farm size, rice yield, variety type, input use, seeds, nitrogen, phosphorus potassium, irrigation water, fertilisers, insecticide, herbicide, no. of operations, land preparation, crop establishment, total labour, crop establishment, harvest & threshing Stochastic frontier analysis (and yield gap)

Most of the explanatory variables used in regression models of irrigated yields and incomes fall into six main categories: natural, physical, human, social, financial and farm management (Table 5-8). This classification mirrors the Sustainable Livelihoods (Scoones 1998), Capitals and Capabilities (Bebbington 1999), Community Capitals (Emery & Flora 2006; Gutierrez-Montes et al. 2009) frameworks, which serve to analyse community development on the basis of a various types of capitals: natural, physical, human, cultural/social, economic/financial, political and/or built.

Table 5-8 **Key factors in irrigated agriculture for yields and farm incomes**

Category	**Definition**	**Key factors in irrigated agriculture**
Human	Skills, ability and physical capability of people to pursue livelihood strategies	Household size, education, marital status, gender, training
Social	Social resources upon which people draw to pursue livelihood strategies	Participation in community organisations, type of irrigation organisation, cooperation/conflict
Financial	Capital base that supports the pursuit of any livelihood strategy	Area, incomes, expenses, asset ownership, livestock ownership, off-farm activities
Natural	Factors relative to natural resources (e.g. water, air, soil, etc.) from which benefits are derived and that exist in a particular location	Precipitation, temperature, soil conditions (type, slope, fertility, nutrients), water quality, agro-climatic zone
Physical	Factors relative to infrastructure supporting livelihood strategies	Water access (volumes, frequency, reliability, etc.), location (distance to main canal, to canal intake, to markets, to main roads)
Farm management	Factors relative to improved agricultural practices	Fertiliser, pesticides, herbicides, agronomic practices, cultivation/harvesting timing, crop variety, infrastructure maintenance, labour use

Source: Author’s adaptation from Scoones (1998), Emery and Flora (2006) and studies cited in Table 5-7

5.3.3 Water, yields and incomes hypotheses

This study extends the literature by using regression analyses to test the association between water access, location, irrigated incomes and yields within the Kiwere and Magozi schemes in southern Tanzania. Based on previous findings in the published literature and earlier chapters of this thesis, the following hypotheses are formulated:

H1.1: Irrigated crop income is positively associated with the adequacy of water supply;
H1.2: Irrigated crop income is negatively associated with the distance between farm and the system's intake;
H2.1: Irrigated crop yields are positively associated with the adequacy of water supply;
H2.2: Irrigated crop yields are negatively associated with the distance between farm and the system's intake.

5.4 Methodology

The purpose of this analysis is to investigate how incomes and yields vary in relation to irrigation variables, particularly water supply and location. The multiple linear regression model and its estimation using Ordinary Least Squares (OLS) is the most widely used analysis technique in econometrics (Schmidheiny 2013), particularly when the dependent variable is continuous and without censoring. Thus, OLS multiple regression models used in this chapter allow identification of the partial effect of water (and other influences) on incomes and yields, while holding the rest of explanatory variables constant. Thus, following Stock and Watson (2003 p. 198), the OLS multiple regression model adopted in this chapter is written in the following form:

$$Y_i = \beta_0 + \beta_1 X_{1i} + \beta_2 X_{2i} + \cdots + \beta_k X_{ki} + u_i, \;\; i = 1, \ldots, n \qquad (5.1)$$

where Y_i is ith observation on the dependent variable (irrigated crop income or irrigated crop yields) and X_{ki} are the ith observations on each of the k regressors and u_i is the error term.

In accordance with the formulated hypotheses (Section 5.3.3), two separate overall analyses were carried out, where the dependent variables are incomes from irrigated crops in the first model (hypotheses H1.1 and H1.2) and crop yields in the second one (hypotheses H2.1 and H2.2).

The first step in each of the analyses is to formulate a model including all independent variables that are theoretically expected to influence incomes and yields. This model is named the theoretical model hereafter. The choice of variables in the theoretical models was made on the basis of previous literature (Section 5.3.2) and findings in Chapter 4. A list of the selected explanatory variables and their definitions is provided in Section 5.5.5. In a second step, a series of stepwise statistical tests are run to empirically remove regressors from the theoretical model to arrive at the proposed specific or final model (Clarke 2014).

Two different variable removal methods are used to verify consistency of results. First a backward elimination procedure is conducted whereby independent variables are eliminated according to a predefined selection criterion (Lai & Ing 2010). This consists of running an OLS regression and then removing the least significant variable, as long as the *p*-value is larger than the specified value to remove (in this case $\alpha=0.10$). Subsequently, the regression is re-run and the elimination process repeated until all remaining variables meet the selection criterion. Regression models were run with robust standard errors to mitigate any potential effect of heteroscedasticity. Second, a general-to-specific algorithm is applied, also with robust standard errors. As Clarke (2014) explains, this consists of running an elimination process by ranking each variable in the theoretical model based on its *t*-statistic and carrying out a series of tests.

Given that there is no strict way to model the functional form of the specification, various versions of the regression models were tested in linear and non-linear forms and their results compared. Various transformations techniques exist (e.g. polynomial, square root, inverse) with logarithmic transformation being one of the most commonly used in the regression analyses of agricultural production (Ahmed et al. 2014; Auffhammer et al. 2012; Barnwal & Kotani 2013; Koirala et al. 2016; Silva et al. 2017). The logarithm function is particularly useful as it allows one to interpret changes in variables as percentage changes (Stock & Watson 2003). Thus, the theoretical regression models in this chapter are formulated and tested in linear, linear-log, log-linear and log-log forms. To avoid the function discontinuity at ln(0), observations with zeros were replaced with a value of one, resulting in ln(1)=0.

After running the four linear and log income models, sensitivity analysis was conducted on the plot location. In 2014, plot locations were noted according to the irrigators' indications, whereas in 2015 the locations were defined using geo-coded data and spatial manipulation techniques (see Section 5.5.4).

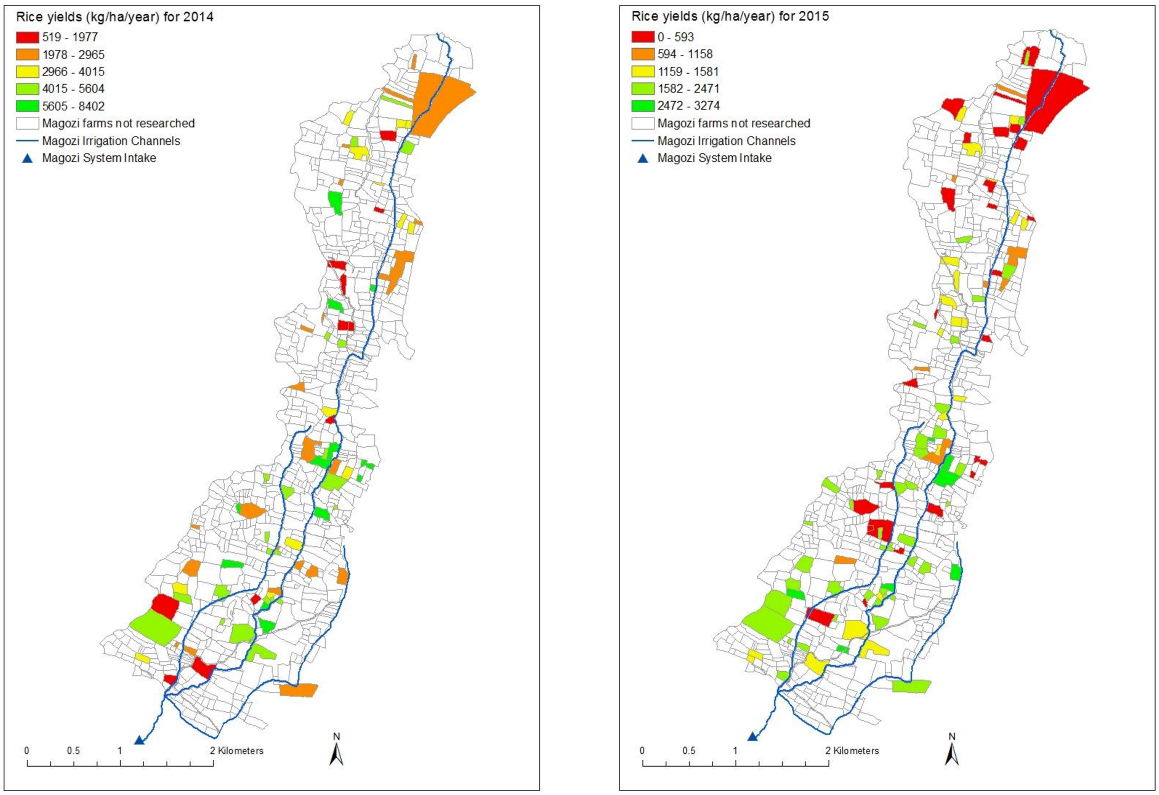
5.4.1 Note on spatial regression analysis

OLS multiple regression models are commonly used for crop yield prediction, yet the assumption of independence among observations may be violated given spatial autocorrelation. Spatial autoregressive models can be used to overcome this limitation, as shown by Florax et al. (2002) and Zhang et al. (2010) in their studies of crop yields.

By observing the thematic maps (Figure 5-1) it appeared that paddy rice yields in Magozi could follow a spatial pattern, which could be investigated using Spatial Lag and Spatial Error models. Here, the validity of spatial models here is highly compromised by the small number of observations resulting in large data gaps between plots. While spatial regression analysis can handle limited data gaps, a large number of missing observations would result in a bias in the error term (Boehmke et al. 2015).

Therefore, spatial variation in yields was explored through OLS regression using independent variables that accounted for farm location. These included distance between farm and main canal, distance between farm and system intake and location within the head/middle/end sections of the scheme.

Figure 5-1 **Spatial representation of rice yields in Magozi**



2014 2015

Source: Author's own maps elaborated with ArcMap using fieldwork data

5.5 Data description and limitations

Three sources of data are used in this analysis: the 2014 baseline survey and the 2015 fieldwork survey and the spatial database (see Data sources, descriptions and limitations for details). Given data gaps and methodological limitations, different data subsets for the income and the yield models are used, as detailed below.

5.5.1 Income analysis in the Kiwere and Magozi schemes

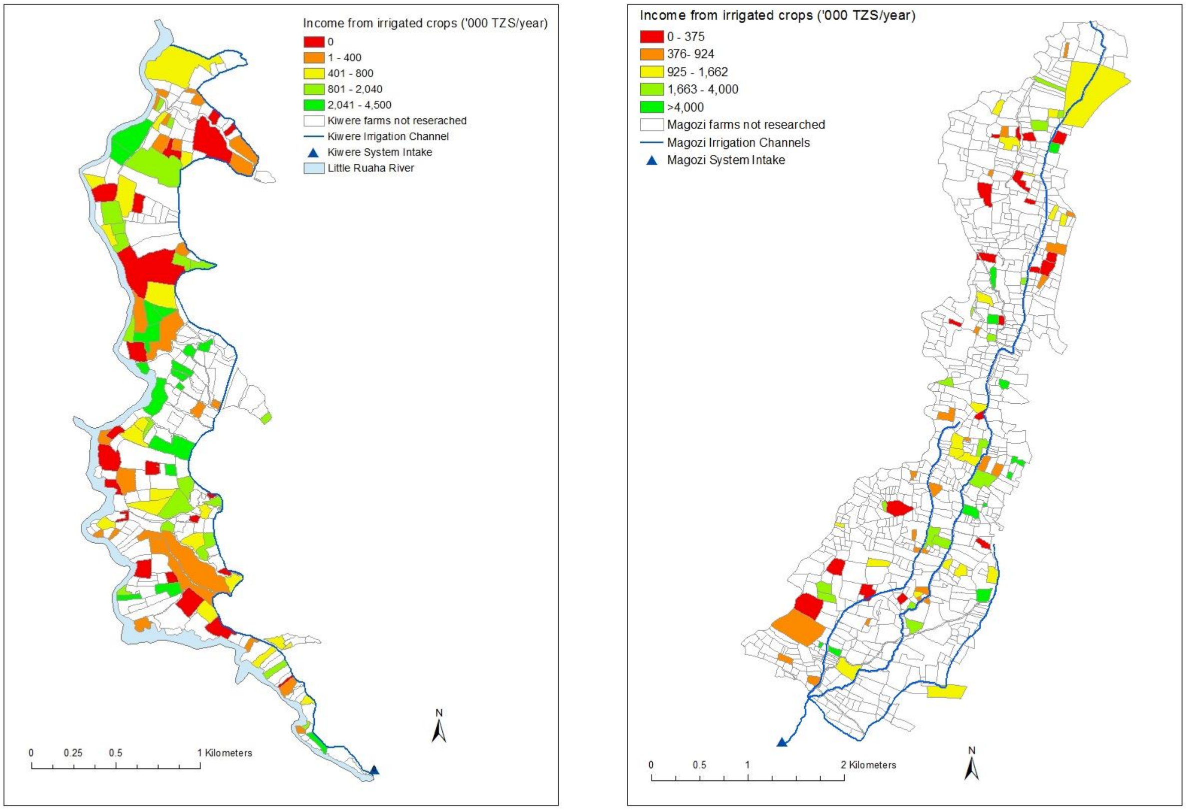
In the analysis of irrigation income, populations from the Kiwere and Magozi schemes are combined to increase the number of observations (with a dummy to indicate the scheme). Regression analyses on each separate scheme was not possible given the small population samples. A two-year cross-sectional dataset was used, combining the 2014 survey (200 households), with 128 of them re-interviewed in 2015 (see Table 2-3).

In this analysis, income from irrigated crops is defined as gross income, also referred to as revenue or cash receipts (Stretch 2014). Here, irrigated income is defined as the cash obtained by irrigators as a result of selling their irrigated crops over a 12-month period, as reported in the 2014 baseline survey (see question 65 in Appendix A). A more accurate way of examining the financial success of irrigation would be to use net income, calculated as cash receipts minus cash costs (Wheeler et al. 2014). However, this is not possible because the baseline survey did not collect data on all cash costs derived from irrigation. Instead, farm expenses (e.g. labour, seeds, transportation, etc.) were recoded conjointly for irrigated and dryland crops. Expenses on herbicide, pesticides and fungicide were recorded as part of a separate question, explicitly referring only to irrigated crops (question 16). Therefore, they can be used as a separate variable in the irrigated crop income model.

Irrigated crop incomes per farm in the Kiwere and Magozi scheme vary considerably within the sampled populations, ranging from zero to over 19 million TZS or 8,500 USD[3] (see summary statistics in Table 5-10). Maps depicting the spatial distribution of incomes in Kiwere and Magozi were created with ArcMap and shown in Figure 5-2.

[3] 1 USD = 2,237 TZS at 07/06/2017 exchange rate

Figure 5-2 **Spatial representation of irrigated crop incomes in Kiwere and Magozi**



Kiwere scheme Magozi scheme

Source: Author's own maps elaborated with ArcMap using fieldwork data

5.5.2 Paddy rice yields in the Magozi scheme

The second regression analysis is based on paddy rice yields in the Magozi scheme. Crop yields in the Kiwere scheme are not included in this analysis because of the high variety of irrigated produce (rice, sorghum, maize, tomatoes, other vegetables and fruits). Given the crops' differences in weight, market value and input requirements, it is very difficult to obtain a measure of yield that would allow a reasonable comparison across both schemes. To compare production levels of various crops, a standard method is to convert the yield of each crop into a crop equivalent yield based on conversions across crop market prices (Dayton-Johnson 1999; Uddin et al. 2009; Vidyavathi et al. 2012). For the purpose of this thesis, such approach has important limitations. First, crop market prices in the Iringa area fluctuate widely over time, so the conversion rates would actually vary within one irrigation season and inter-annually. Second, there is no historic information on crop prices in Iringa that would allow an accurate estimation of crop equivalences at the time of production. In Magozi, rice is the only irrigated crop, with the exception of some minor sorghum production. Such homogeneity facilitates the comparative study of paddy rice yields across the scheme.

Given that the Magozi population sample is relatively small (n=100), the number of observations was maximised by combining data from 2014 and 2015. Information on irrigated area, production and water supply was recorded both in 2014 and 2015, thus allowing two sets of observations to be generated, i.e. one for each year. Variables that only have data for one year (e.g. education) are assumed to remain unchanged. Thus, stacking up the regression equations into one combined model obtains:

$$y = \begin{bmatrix} y_1 \\ y_2 \\ \vdots \\ y_n \\ \vdots \\ y_p \end{bmatrix} = \begin{bmatrix} \beta_0 \\ \beta_0 \\ \beta_0 \\ \vdots \\ \vdots \\ \beta_0 \end{bmatrix} + \begin{bmatrix} X_{11} & X_{12} & \dots & X_{1k} \\ X_{21} & X_{22} & \dots & X_{2k} \\ \vdots & \vdots & \ddots & \vdots \\ X_{p1} & X_{p2} & \dots & X_{pk} \end{bmatrix} \begin{bmatrix} \beta_1 \\ \beta_2 \\ \vdots \\ \beta_k \end{bmatrix} + \begin{bmatrix} \epsilon_1 \\ \epsilon_2 \\ \vdots \\ \epsilon_n \\ \vdots \\ \epsilon_p \end{bmatrix} \tag{5.2}$$

where *n* is the number of observations for 2014, *p*-*n* is the number of observations for 2015, *p* is the total number of observations and *k* is the number of regressors (explanatory variables) included in the model. This model is run with clustered standard errors to account for pairs of values (2014 and 2015) corresponding to the same household, given the two year panel nature of the two year cross-sectional dataset[4].

In this analysis, rice output in measured by the weight (in kg) of paddy. Strictly speaking, paddy refers to harvested, un-milled rice with its protective husk in place (RGA 2017). Conversely, rice refers to the grain after removal of the husk (brown rice), germ and bran (white rice). Unlike most grains that are weighted clean and dry, rice production (and yields) is generally reported in terms of paddy instead of milled rice (FAO 2011). In the Magozi scheme, irrigators weight their

[4] A fixed effects model for panel data could not be estimated since most of the variables of interest do not vary between the two years. In addition, a random effects model for panel data has a too strong assumption on the error term and, hence, is not appropriate. Therefore, a pooled regression model with clustered standard errors was used, following the example of Baylis et al. (2011), who model the effects of agro-climatic and human variables on farm value .

paddy during the bagging process, where each bags equates to 50 kg (Figure 5-3). However, it should be noted that the terms paddy, rice paddy and rice are often used interchangeably in the literature (Becker & Johnson 1999; Mghase et al. 2010; Saito et al. 2015).

Figure 5-3 **Paddy bags in Magozi in July 2015**

Source: Author's own photo from fieldwork

An important consideration in crop productivity calculations is the distinction between sown and harvested area. Due to various reasons, e.g. resource constrains or adverse climatic conditions, certain areas planted or sown may not be harvested (FAO 2011). Data collected during the 2015 survey shows important differences in sown and harvested areas for a number of rice growers in Magozi. Reportedly, failed harvests in 2015 were a result of reduced rainfall, low river flows and consequent water scarcity within the irrigation system (see Section 4.5.1). Interviewees also noted that during the previous season (2014) water availability had not been such a significant issue. Meteorological data recorded in the Iringa station (The United Republic of Tanzania 2016) shows that annual rainfall in 2015 was almost 40 percent lower than in 2014, i.e. 555 mm and 885 mm, respectively.

Crop output per harvested area responds to the proper definition of yields, which is used in international crop statistics (OECD 2015) and most commonly in the literature − e.g., Kato et al. (2006); Sadras and Bongiovanni (2004); and Hussain et al. (2004). Nevertheless, a number of studies employ other measures of area, such as total irrigated area (Battese & Coelli 1992), sown area (Barnwal & Kotani 2013) and farmland area (Kurukulasuriya et al. 2011; Tittonell et al. 2007). In this chapter, irrigated (sown) area is used for a number of reasons. First, data on 2014 irrigated area does not distinguish between sown and harvested land. Second, using total irrigated area is of particular interest as it allows us to consider the effects of water scarcity on land abandonment and rice productivity, as reported qualitatively in Magozi.

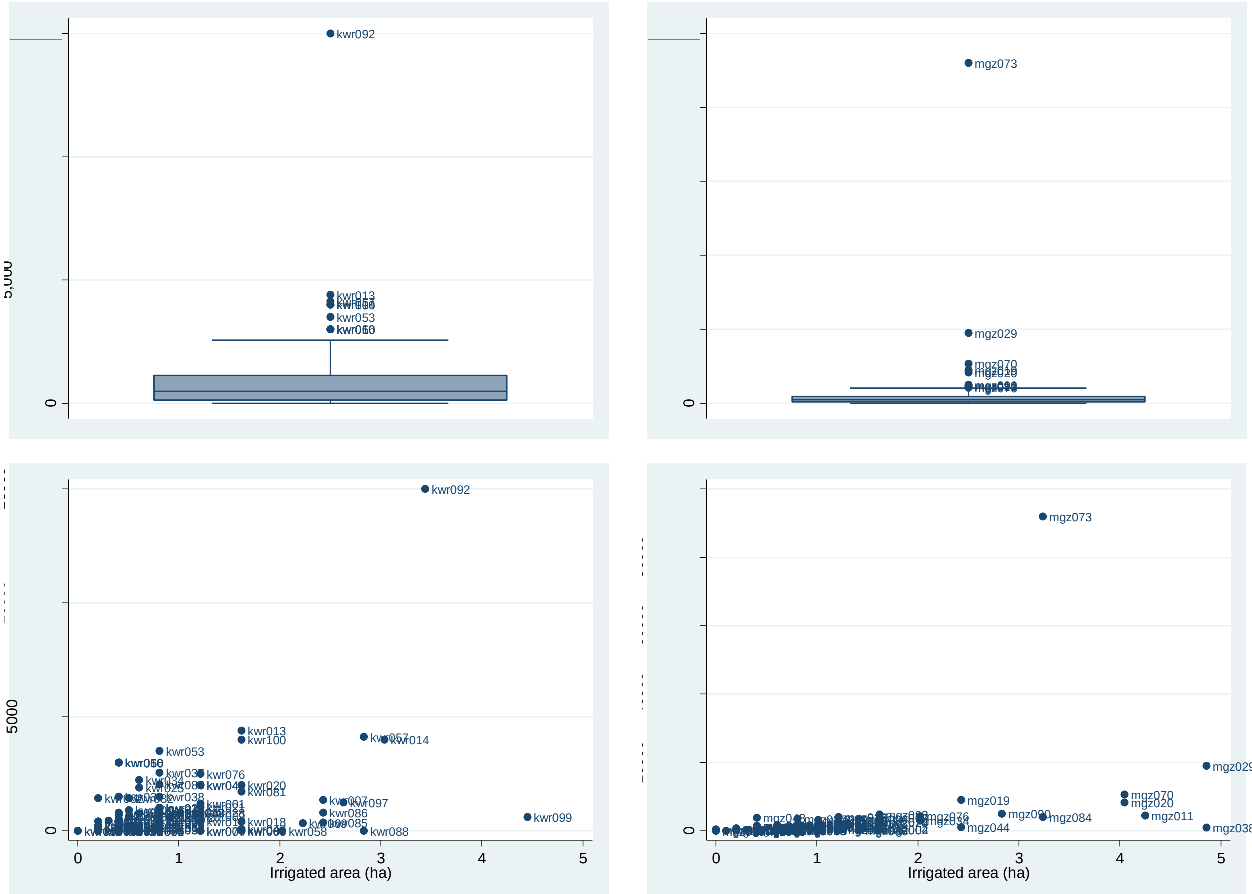
5.5.3 Detection of outliers

Unusual values, often referred to as outliers, can be a result of errors or may carry important information. The exact characterisation depends on the underlying assumptions and detection method, but a general definition of an outlier is an observation that appears to be inconsistent with the rest of the data (Ben-Gal 2005). A number of advanced statistical techniques exist (Ibid.) to detect abnormal values in large, complex datasets. Conversely, when dealing with small sample sizes and a limited number of unusual values, other techniques such as summary statistics and graphical methods are particularly useful (Williamson et al. 1989).

In the Kiwere and Magozi income model, two outliers in the income variable were detected (respondent codes ‘kwr092’ and ‘mgz073’ in Figure 5-4). Considering the economic context of both schemes, such extreme values are highly improbable and therefore it is reasonable to assume that they are errors. In a sensitivity analysis, regression models in linear form were run with and without the possible outliers. After the elimination process, the model in which all observations were kept had an adjusted-R^2 of 0.39 and only four statistically significant explanatory variables. Conversely, the regression without unusual income observations had an *adjusted*-R^2 of 0.49 and 11 significant regressors. Given the abnormality of extreme incomes and the poor performance of the model, the two income outliers were dropped from the sample. Fertiliser expenses and tomato production also presented one abnormal observation each. However, dropping these observations did not significantly affect the results or performance of the models and, hence, they were kept.

In the Magozi rice yield model outliers in the dependent and independent variables were investigated following the same process. No unusual values were found and hence no observations were dropped from the sample.

Figure 5-4 **Box and scatter plots of irrigated income and irrigated area by scheme**



Kiwere Magozi

Source: Author's computations in Stata

5.5.4 Spatial manipulation

One of the key variables of interest in this chapter is location of the farm plots, which is hypothesised to influence incomes and yields. In the agricultural literature, location is often referred to as the position within the head, middle or tail sections on an irrigation scheme. In this chapter, location is analysed in various ways.

First, based on the 2014 survey data, location is defined as a trichotomous variable according to the interviewees' responses to the question: 'Where is your plot located? Head, middle or tail section of the scheme?'

Second, using Geographic Information System (GIS) data collected in 2015, plot location was defined as a continuous variable (in m or km) representing two distances: a) between farm and irrigation canal ('transversal distance') and b) between farm and system intake. Using the digital files provided by Tanzanian research colleagues (see Section 2.4.3), spatial analyses were carried out with ArcMap 10.3.1 software. First, for each farm plot (polygon) 'near analysis' function was used to identify the closest point on the irrigation canals. Because there is no data available on distributary canals, it was assumed that for each plot, the closest point on the irrigation canals is its' off-take. The distance between the farm polygon and the off-take was recorded as the transversal distance. Second, 'network analysis' function was used to calculate the linear distance along the main irrigation canals between the farm off-take points and the system intake. A graphical example of the distance calculations is presented in Appendix F.

In Kiwere and Magozi, families often own and/or rent multiple plots located in scattered locations across the irrigation schemes. Because the survey data in this thesis are associated to households and not farms, an adjustment in distances is needed to be made for households cultivating multiple plots. In these cases, distances were calculated as a weighted average across all plots. The weighted average distance takes into account the size of each plot, assuming that the larger the size, the greater the importance for crop production:

$$WD_i = \frac{\sum_{j=1}^{n} D_j A_j}{\sum_{j=1}^{n} A_j} \tag{5.3}$$

where, WD_i is the weighted average distance of household *i*, *n* is the number of plots own/rented by household *i*, D_j is the distance associated with plot *j* and A_j, is the area of plot *j*. For households with one single plot, $WD_i = D_j$.

Weighted average distances expressed in meters (or km) can be used only when analysing each scheme separately. This is because the Kiwere and Magozi schemes differ significantly in size (6.8km and 9.4km, respectively in the main canal length) and, therefore, the same distance would not reflect the same proximity to the intake. Thus, relative distance was expressed as the ratio of the distance between farm plot and system's intake over the total system's length. The formula is:

$$RD_i = \frac{WD_i}{L} \tag{5.4}$$

where, RD_i is the relative distance of household *i*, WD_i *n* is weighted average distance of household *i* and *L* is the length of the main canal.

The third method consisted of converting relative distances into a trichotomous scale (head, middle, end), which is common in the literature. Schemes were divided in three equal parts, each measuring one third of the total length. The formula is as follows:

$$LOC_i = \begin{cases} Head & if \quad RD_i < 1/3 \\ Middle & if \quad 1/3 \leq RD_i < 2/3 \\ Tail & if \quad RD_i \geq 2/3 \end{cases} \tag{5.5}$$

where LOC_i is the location in trichotomous scale of household i and RD_i is the relative distance of household i.

5.5.5 Variable description

The variables in the income and yield models were selected from each of the six 'capitals', as detailed in Section 5.3.2 and Table 5-8. Based on the literature review, the expected sign (e.g. positive or negative) of each variable on irrigated crop incomes and yields is provided in Table 5-9. Both dependent variables of income and yield are hypothesised to be influenced in the same direction by each independent variable below. In those cases where the literature provides mixed results, a question mark is used to indicate mixed results. Summary statistics and definitions of all model variables are provided in Table 5-10.

Table 5-9 **Modelled variables for income and yield models**

Category	Variables
Human	Female gender (-), Age (?), Education (+), Household size (+)
Social	Irrigation scheme (?)
Financial	Crop production (+), Area (+), Off-farm income (?), Asset ownership (+)
Natural	Soil fertility (+), Clay soil (+), Sandy soil (-), Year (?)
Physical	Perception on Equity of water distribution (+), Satisfaction with water supply (+), Timing of water supply-End (-), Distance to intake (-), Distance to main canal (-)
Farm management	Herbicide, pesticide and fungicide input (+), Fertiliser input (+)

Table 5-10 **Variable description and summary statistics for the income and yield models**

Variable	Definition	Model	N	Mean	Std.Dev.	Min	Max
Gender (dummy)	Gender of household head 0= male; 1=female	Income	200	0.13	0.34	0	1
		Yield	248	0.19	0.39	0	1
Age	Age of the of household head	Income	196	43.54	13.26	18	91
		Yield	200	42.76	13.08	18	77
Education of household head (dummy)	0= no education or some primary; 1= completed primary education or beyond	Income	196	0.79	0.40	0	1
		Yield	198	0.81	0.39	0	1
Household size	Number of people living in the household	Income	200	5.71	2.17	1	10
		Yield	200	5.46	2.01	1	10
Scheme (dummy)	0= Kiwere; 1= Magozi	Income	200	0.50	0.50	0	1
Irrigated income	Gross income from irrigated crops in ‘000 TZS	Income	198	1,292	1,994	0	19,001
ln (Irrigated income)	Natural logarithm of gross income from irrigated crops in '000 TZS	Income	198	5.96	2.27	0	9.85
Rice production	Annual rice production in kg	Income	200	1,994	4,002	0	30,150
Maize production	Annual maize production in kg	Income	200	2,099	5,093	0	48,000
Tomato production	Annual tomato production in kg	Income	200	3,072	26,106	0	360,000
Sorghum production	Annual sorghum production in kg	Income	200	90	623	0	8,000
Onion production	Annual onion production in kg	Income	200	310	2,060	0	24,000
ln (Rice production)	Natural logarithm of annual rice production in kg	Income	200	4.01	3.96	0	10.31
ln (Maize production)	Natural logarithm of annual maize production in kg	Income	200	4.19	3.81	0	10.78
ln (Tomato production)	Natural logarithm of annual tomato production in kg	Income	200	1.73	3.32	0	12.79
ln (Sorghum production)	Natural logarithm of annual sorghum production in kg	Income	200	0.40	1.61	0	8.99
ln (Onion production)	Natural logarithm of annual onion production in kg	Income	200	0.47	1.88	0	10.09
Production of other irrigated crops (dummy)	0=no other irrigated crops produced; 1=other irrigated crops produced	Income	200	0.07	0.25	0	1
Paddy yields	Paddy yield in kg/ha/year	Yield	170	2,828	1,846	0	10,383
ln (Paddy yields)	Natural logarithm of paddy yield in kg/ha/year	Yield	170	7.43	1.85	0	9.25
Irrigated area	Area under irrigation in 2013/14 season, in m^2	Income	200	10,152	8,985	0	4,856
		Yield	174	10,451	9,767	0	60,703
ln (Irrigated area)	Natural logarithm of area under irrigation in 2013/14 season in sqm	Income	200	8.78	1.45	0	10,79
		Yield	174.00	8.83	1.38	0	11.01
Off-farm income (dummy)	0=household has no off-farm income; 1=household has some off-farm income	Income	200	0.70	0.46	0	1
Water pump (dummy)	1=ownership of borehole or water pump; 0=otherwise	Income	199	0.05	0.22	0	1
Mobile phone (dummy)	1=ownership of mobile phone; 0=otherwise	Income	199	0.77	0.42	0	1
Farm tools (dummy)	0= Ownership of only hand tools; 1= ownership of animal or motor-driven farming tools	Yield	200	0.19	0.39	0	1
Soil fertility (dummy)	0= infertile or moderately fertile; 1= very fertile	Income	199	0.27	0.45	0	1
		Yield	200	0.45	0.5	0	1
Sandy soil (dummy)	1= Sandy; 0=other	Income	199	0.28	0.45	0	1

Table 5-10 **Variable description and summary statistics for the income and yield models**

Variable	Definition	Model	N	Mean	Std.Dev.	Min	Max
Clay soil	1= Clay; 0=other	Income	199	0.38	0.49	0	1
Year (dummy)	0= 2014 observation; 1= 2015 observation	Yield	236	0.50	0.50	0	1
Perception of equity of water distribution	Agreement with the statement 'water is equitably distributed among the irrigators in your irrigation system': 1= Totally disagree, 2=Disagree, 3=Neutral/Don't know, 4=Agree, 5=Strongly agree	Income	197	3.29	1.13	1	5
		Yield	175	2.74	1.04	1	5
Satisfaction with water supply	1= Very dissatisfied, 2= Dissatisfied, 3=Neutral/Don't know, 4= Satisfied, 5= Very satisfied	Income	197	3.49	1.01	1	5
		Yield	176	3.14	1.12	1	5
Timing of water supply (dummy)	1= only receive water at the end of the irrigation season, 0 = otherwise	Yield	152	0.29	0.46	0	1
Reported head location (dummy)	Head location reported by interviewee where 0= Middle or tail; 1= Head	Income	195	0.29	0.45	0	1
Reported tail location (dummy)	Tail location as reported by interviewee where 0= Head or middle; 1= Tail	Income	195	0.18	0.38	0	1
Geo-coded head location (dummy)	Conversion from relative distance where 0= Middle or tail; 1= Head	Income	126	0.44	0.5	0	1
		Yield	144	0.44	0.5	0	1
Geo-coded tail location (dummy)	Conversion from relative distance where 0= Head or middle; 1= Tail	Income	126	0.22	0.42	0	1
		Yield	144	0.24	0.43	0	1
Relative distance to intake	Distance from farm off-take to system intake over total canal length	Income	126	0.40	0.26	0	1
Distance to canal	Average weighted distance between farm plot and irrigation canal in km	Yield	144	108	135	0	573
Distance to intake	Average weighted distance between farm off-take and system intake in km	Yield	144	3,916	2,587	196	9,380
Herbicide, pesticide and fungicide input	Annual expenses ('000 TZS) of herbicide, pesticide and fungicide	Income	200	88	215	0	1,610
	Annual expenses (TZS) of herbicide, pesticide and fungicide per ha	Yield	194	14,706	15,146	0	84,016
ln (Herbicide, pesticide and fungicide input)	Natural logarithm expenses of herbicide, pesticide and fungicide	Income	200	2.83	1.96	0	7.38
	Natural logarithm expenses of herbicide, pesticide and fungicide per ha	Yield	194	6.58	4.66	0	11.34
Fertiliser input	Annual expenses ('000 TZS) of fertiliser	Income	200	450	2,865	0	40,400
ln (Fertiliser input)	Natural logarithm of annual expenses ('000 TZS) of fertiliser	Income	200	2.89	3.07	0	10.61

5.6 Results from the irrigated crop income models in Kiwere and Magozi

5.6.1 General model considerations

Correlations and Variance Inflation Factors (VIFs) among model regressors were checked for serious multicollinearity. Onion and tomato production had the strongest correlation (r= 0.80), which can be explained by households' preferences in terms of crop selection. Second, clay and sandy soil types had a relatively high correlation (r = -0.49), which can be explained because they are both dummies coded from the original soil type categorical variable. Rice production was correlated with scheme (r = 0.48) and irrigated area (r = 0.49), which is because rice is the predominant crop in Magozi and is usually cultivated over larger areas, compared to horticultural crop that are most common in Kiwere. The mean VIFs for specific models did not exceed 1.70, while the highest VIF score for any of the independent variables was tomato production (3.15) in the linear model. Hence, it was concluded that there was no serious multicollinearity present in the final models (i.e. no VIFs over 5), and no variables were dropped in the regression.

In this chapter, all models results were checked for robustness. The results from the backward elimination process and the general-to-specific method are generally consistent. With the exception of the linear model in the general-to-specific method, all the rest show robustness of results in the selection of significant regressors and their coefficients. In the first linear model, 11 out of 24 independent variables remain significant at least at the 0.10 level, whereas in the rest, only eight variables or less remain significant at this level after the elimination process (see Table 5-11). The linear models have a reasonable overall fit based on their *adjusted-*R^2 (0.49 and 0.47), considerably better than the linear-log model (*adjusted-*R^2 = 0.22). However, the *adjusted-*R^2 cannot be used to compare linear and log models, as the dependent variables are not the same (one is Y_i and the other is $\ln(Y_i)$).

5.6.2 Hypotheses testing

The first hypothesis that irrigated crop income is positively associated with the adequacy of water supply is not supported by the results of the regression analysis given that the independent variable satisfaction with water supply is not significant across all models. This suggests that perceptions of adequacy of supply are not significant for irrigated crop incomes when other more relevant human and financial factors are controlled for. This is consistent with information gathered during qualitative interviews, as many irrigators explained that (besides water access) differences in capital (including land assets) were one of the main factors contributing to the economic divide within their communities.

The second hypothesis (irrigated crop income is negatively associated with the distance between farm and the system's intake) is supported by the linear and linear-log models, which indicate that (reported) location in the tail-end of the schemes has a negative effect on irrigated crop incomes. Interestingly, the log-linear model suggests that (reported) head-end location also has a negative effect on incomes. The implication of these results is that the effect of distance between farm and intake may not be linear, but actually cluster around head, middle and tail areas of the schemes. In a sensitivity test, two models were tested using GIS-calculated farm location (continuous distance and trichotomous variables), as described in Section 5.5.4. Both models resulted in the same specific model, where location measured with GIS methods is not significant at the 0.10 level. Linear distances were centred and squared to check the presence of a quadratic, U-shape relationship, but the variable was not significant. Contrasting results between reported and GIS locations could be due to the variation in population sub-sample, as not all households had spatial data available. Moreover, self-reported location is subject to irrigators' understating of the entire scheme. In some cases, irrigators seemed to associate their farm location to their place of residence. This was particularly marked in the Magozi scheme, where the farming community is split into three villages, Magozi, Ilolo mpya and Mkombilenga, which are aligned with the head, middle and end sections of the irrigation system (see Magozi map in Appendix C).

5.6.3 Other variables of interest

Out of the four household characteristic variables, age, household size and education are statistically significant (at least at the 0.10 level) across several models. Age is found to have a negative statistically significant influence on irrigated incomes, contrasting with some previous research (Safa 2005) suggesting age was not significant for farm incomes. The influence of age in Magozi and Kiwere could be explained by the greater capacity of the young to undertake physically demanding irrigation work. Moreover, the willingness of younger irrigators to adopt innovative, more profitable farming practices could be explored as another linkage between age and incomes. The positive and statistically significant influence of household size may indicate the important contribution of children or elderly to family livelihoods, as noted by Wan (2004). By contrast to the short-term benefits, employing school-age family members in irrigation could become detrimental for their long-term wellbeing, if their formal education were to become compromised. Notably, during qualitative discussions, a few interviewees mentioned that, because of their poor financial situation and uncertainty of water supply, they were unable to employ professional labourers. Instead − chiefly in Magozi – irrigators often have to engage their own children to assist with farming activities whenever required, although this may conflict with regular school attendance or even important activities, such as end-of-year examinations.

Household head's education level is statistically significant across most models, yet it has an unexpected negative sign. Given this unusual association, sensitivity tests were carried out using education level of the head's spouse and a combination of head and spouse's education levels. Different scales (binary and multilevel) were also tested. Regardless of how education was accounted for, the results were statistically insignificant or significant with a negative coefficient. A possible explanation could be that educated households are more focused on other highly skilled activities, thus relying less on irrigation. Thus, it could be expected that a) households with higher education levels earn higher incomes from non-irrigated activities and b) non-irrigated incomes represent a greater portion of their total earnings. Kolmogorov-Smirnov and Mann-Whitney non-parametric tests of statistical significance showed no difference in non-irrigated incomes, neither in absolute figures nor as a proportion of total household incomes. Therefore, the negative influence of education on irrigated incomes remains unexplained.

Gender of the household head is not statistically significant at the 0.10 level for irrigation incomes across all models. While this may seem to contradict conventional wisdom, there is increasing evidence that female-headed households in sub-Saharan Africa are not necessarily income-disadvantaged and that gender inequalities are not always well captured by only observing household headship (IFAD 2001; van Koppen et al. 2007). Hence, the influence of gender was also tested using a decision-making index[5] developed by Bjornlund et al. (2017b) for

[5] For each production type (irrigated crops; rain-fed crops; cattle; and small stock) the index was created by summing up six decisions on: i) crop/animal; ii) implements; iii) input; iv) work schedule; v) selling produce/animals; and vi) use of farming proceeds, and rescaled to five decision-making categories: decisions made

the six irrigation schemes included in this thesis. The index reflects the relative level of participation of men and women in decisions regarding irrigation and overall household matters. Two forms of the index were tested – for irrigated crops and overall farming decisions – both alone and in combination with household head gender dummy. In none of the cases was the decision-making index significant, hence confirming the results found from the simple dummy of gender.

As expected from the literature review, irrigated area is statistically significant and positively associated with irrigated crop incomes. Households cultivating greater areas have the potential to obtain greater agricultural outputs and, in turn, earn greater revenues from selling their crops. This finding is consistent with numerous previous studies highlighting the association between landholding disparities and the distribution of agricultural benefits (Hussain & Hanjra 2003; Lipton et al. 2003; Maskey et al. 1994; van Etten et al. 2002). Such a connection was also noted by irrigators in Kiwere and Magozi (see Section 4.5.2), and noted as one of the key mechanisms linking irrigation water supply and socio-economic inequalities within the farming communities. Indeed, households with higher incomes are in a better position to expand their irrigation activities by buying more land. In turn, greater irrigated area provides an opportunity to increase their incomes. This creates a feedback loop whereby wealth inequalities (landholding and incomes) may be exacerbated by irrigation.[6]

Production of rice and high-value crops (onion and ‘other’) are statistically significant and positively associated with incomes. This link is consistent with the findings in Chapter 4, indicating that yields are connected to economic inequalities. Tomato production (linear and log) is statistically significant across five models, yet the sign is inconsistent between the linear and logarithmic forms. During fieldwork in 2015, it was observed that many irrigators struggled to sell their tomatoes either due to oversupply relative to the market demand or poor quality of the

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by 1—all females; 2—mainly females; 3—balanced between females and males; 4—mainly by males; 5—all males. An overall gender decision--making index was also defined by taking the average of the four production types

[6] Endogeneity issues in the model are not expected given that current season irrigation land input is used as an independent variable for current season irrigation crop revenue as a dependent variable. Hence, there should be no reverse causality, i.e. current season irrigation crop revenue should not be a predictor of current season irrigation land input.

produce. In fact, tomatoes grown in Kiwere were often affected by pests and diseases that are common in the Iringa region (MUVI-SIDO 2009). Such results raise questions about the importance of crop selection as a strategy to increase livelihoods, chiefly in the Kiwere scheme where a wide range of products can be cultivated.

Table 5-11 **OLS regression model results of irrigated crop income in Kiwere and Magozi schemes**

	Theoretical model	**Backward elimination**					
Independent variables	**Linear**	**Linear**	**Linear-Log**	**Log-Linear**	**Log-Log**	**Linear GIS distance**	**Linear GIS dummies**
Gender	99.80 (232.85)	.	.	.	.	.	.
Age	-14.67* (8.25)	-15.57** (6.42)	.	-0.04** (0.02)	-0.03** (0.01)	-12.55** (6.11)	-12.55** (6.11)
Education	-407.51* (211.87)	-427.36** (200.80)	.	-1.02*** (0.36)	-0.80** (0.31)	-71062.1977	-71062.1977
Household size	11.16 (68.45)	.	.	0.19** (0.09)	0.16** (0.08)	.	.
Scheme	229.65 (330.02)	.	.	.	2.34*** (0.44)	.	.
Rice production	0.18* (0.11)	0.19** (0.09)		0.00*** (0.00)		0.18* (0.10)	0.18* (0.10)
ln (Rice production)			189.32*** (51.93)		.		
Maize production	-0.03 (0.02)	-0.0008		.		.	.
ln (maize production)			.		.		
Tomato production	-0.02*** (0.01)	-0.02*** (0.01)		.		-0.01** (0.01)	-0.01** (0.01)
ln (Tomato prod.)			.		0.12* (0.07)		
Sorghum production	-0.02 (0.08)	.		.	.	.	.
ln (Sorghum prod)			-110.00** (46.19)		.		
Onion production	0.16** (0.07)	0.17** (0.07)		.		0.15* (0.08)	0.15* (0.08)
ln (onion production)			.		.		
Other irrig. crops	875.35** (373.60)	677.79* (366.59)	.	.	.	705.57* (380.20)	705.57* (380.20)
Irrigated area	0.10*** (0.03)	0.10*** (0.03)		0.00* (0.00)		0.10*** (0.03)	0.10*** (0.03)
ln (Irrigated area)			538.31* (292.34)		0.46*** (0.12)		
Off-farm income	-309.52 (237.12)	.	.	.	.	.	.
Mobile phone	308.68 (239.36)	.	477.47** (225.27)	.	.	.	.
Water pump	-555.27 (579.09)	.	.	.	.	.	.
Soil fertility	572.07** (274.52)	638.25** (284.68)	599.27* (332.16)	.	.	463.35* (279.48)	463.35* (279.48)
Clay soil	213.27 (298.11)	.	.	.	.	.	.
Sandy soil	515.85* (294.94)	400.05* (240.54)	505.80* (305.50)	.	.	.	.
Equity of distribution	133.82 (124.11)	.	.	.	.	.	.
Satisfaction water supply	-25.82 (158.46)	.	.	.	.	.	.
Reported head location	51.34 (338.03)	.	.	-0.91** (0.40)	.	.	.
Reported tail location	-667.11*** (218.20)	-707.30*** (222.56)	-1,055.48*** (308.65)	.	.	.	.
Distance to intake						.	
Geo-coded head (dummy)							.
Geo-coded tail (dummy)							.
Fertiliser input	0.01 (0.01)	.		.	.	.	.
ln (Fertiliser input)			.		.		
Herb. pest, fungicide	0.67 (0.62)	.		.	.	.	.
ln (Herb. pest, fungi)			201.01*** (58.46)		0.24** (0.10)		
Constant	45.78 (902.53)	796.90** (378.14)	-5,262.42** (2,496.99)	6.96*** (0.74)	0.66 (1.12)	586.79 (382.47)	586.79 (382.47)
Observations	186	186	194	186	190	189	189
R-squared	0.53	0.52	0.29	0.21	0.34	0.49	0.49
Adjusted R-squared	0.534	0.49	0.26	0.19	0.32	0.47	0.47
F-Statistic	4.123***	3.31***	4.825***	8.017***	14.5***	4.142***	4.142***

.Variables are statistically insignificant at the 0.10 level and dropped from the final model; *** $p < 0.01$, ** $p < 0.05$, * $p < 0.10$; Blanks indicate variables are not included in the models
Standard errors in parenthesis

Table 5-11 **OLS regression model results of irrigated crop income in Kiwere and Magozi schemes (cont')**

	General – to - Specific					
Independent variables	**Linear**	**Linear-Log**	**Log-Linear**	**Log-Log**	**Linear GIS distance**	**Linear GIS dummies**
Gender	.	.	.	.	.	.
Age	.	.	-0.03** (0.01)	-0.03** (0.01)	.	.
Education	.	.	-0.92*** (0.35)	-0.80** (0.31)	-0.84*** (0.29)	-0.87*** (0.29)
Household size	.	.	0.20** (0.09)	0.16** (0.08)	.	.
Scheme	.	.	1.09*** (0.33)	2.34*** (0.44)	1.46*** (0.32)	1.28*** (0.30)
Rice production	.		0.00* (0.00)		.	.
ln (Rice production)		189.32*** (51.93)		.		
Maize production	.		.		.	.
ln (maize production)		.		.		
Tomato production	.		.		.	.
ln (Tomato prod.)		.		0.12* (0.07)		
Sorghum production	.	.	.	.	.	.
ln (Sorghum prod)		-110.00** (46.19)				
Onion production	.		.		.	.
ln (onion production)		.		.		
Other irrig. crops	.	.	.	.	.	.
Irrigated area	.		0.00** (0.00)		0.00*** (0.00)	0.00*** (0.00)
ln (Irrigated area)		538.31* (292.34)		0.46*** (0.12)		
Off-farm income	.	.	.	.	.	.
Mobile phone	.	477.47** (225.27)	.	.	0.89** (0.39)	0.90** (0.39)
Water pump	.	.	.	.	.	.
Soil fertility	.	599.27* (332.16)	.	.	.	.
Clay soil	.	.	.	.	.	.
Sandy soil	.	505.80* (305.50)	.	.	.	.
Equity of distribution	.	.	.	.	.	.
Satisfaction water supply	.	.	.	.	.	.
Reported head location	.	.	-0.74* (0.40)			
Reported tail location	.	-1,055.48*** (308.65)	.			
Distance to intake					.	
Geo-coded head (dummy)						.
Geo-coded tail (dummy)						.
Fertiliser input	.		0.00* (0.00)		.	.
ln (Fertiliser input)		.		.		.
Herb. pest, fungicide	.		.		0.00** (0.00)	.
ln (Herb. pest, fungi)		201.01*** (58.46)		0.24** (0.10)		
Constant	1,291.69*** (141.72)	-5,262.42** (2,496.99)	6.08*** (0.74)	0.66 (1.12)	4.36*** (0.42)	4.53*** (0.41)
Observations	198	194	186	190	189	189
R-squared	0.00	0.29	0.25	0.34	0.49	0.49
Adjusted R-squared	0.00	0.26	0.22	0.32	0.47	0.47
F-Statistic	0.00	4.825***	7.769***	14.5***	4.142***	4.142***

.Variables are statistically insignificant at the 0.10 level and dropped from the final model; *** p < 0.01, **p < 0.05, *p < 0.10; Blanks indicate variables are not included in the models
Standard errors in parenthesis

Table 5-12 **Summary statistics and significance tests for non-irrigation income by education level**

Income from non-irrigated activities ('000 TZS)	**N**	**Mean**	**Median**	**Std.Dev**	**Min**	**Max**	**K-S *p***	**WRS *z***
Under primary education	40	1,144	443	1,683	0	6,721	0.454†	-0.87†
Primary education or beyond	156	1,225	615	2,075	0	18,500		
Proportion non-irrigated income over total gross income	**N**	**Mean**	**Median**	**Std.Dev**	**Min**	**Max**	**K-S *p***	**WRS *z***
Under primary education	40	0.41	0.39	0.33	0.00	1.00	0.398†	-1.252†
Primary education or beyond	153	0.48	0.48	0.35	0.00	1.00		

† The values are not statistically significant at p<0.10

5.7 Results from the paddy rice yield models in Magozi

5.7.1 General model considerations

Checking for multicollinearity, the greatest correlation coefficient is found between timing of water supply and tail location (r = 0.67). This can be explained by the fact that plots located at the tail-end tend to receive water later in the season. Water supply satisfaction and year are also correlated (r = -0.65), which responds to greater water scarcity in 2015, as reported in qualitative interviews. The mean VIF for the various 'tested down' models was less than 1.74, with no regressors having a VIF score greater than 2.79 (tail location in the log-linear model), indicating no serious multicollinearity was present and hence no variables were dropped.

The backward elimination and general-to-specific methods converge into nearly identical final models, with the exception again of the linear model. The log-linear and log-log models have eight statistically significant variables and a reasonably good fit (*adjusted-*R^2= 0.43), and thus are considered to be the preferred models. The models in which location is tested as a trichotomous variable result in a different set of regressors compared to the models using distance to intake, although there is consistency across certain variables.

5.7.2 Hypotheses testing

Hypothesis 2.1 (that crop yields are positively associated with adequacy of water supply) is supported by the results of the regression analyses. Across the various yield models, the level of water supply satisfaction is positively associated with paddy yields. Assuming that irrigators' level of satisfaction is an accurate proxy of adequacy of water supply, the results of this analysis are consistent with the common view that improved water supply results in higher yields (Makombe & Sampath 1998).

The hypothesis that rice yields are negatively associated with the distance between a farm and the intake of the irrigation system (H2.2) is not directly supported by the results of this analysis, although there are important location differences. While distance between farm and intake as a continuous variable is not statistically significant, location dummies for head and tail sections are good predictors of paddy yields. Interestingly, both appear to have a negative effect on yields with 'tail' having a stronger effect (greater coefficient in absolute value). While head-enders are typically regarded as having a location advantage over the rest, these results show that it is actually the middle section where higher (mean, median and maximum) yields are achieved (Table 5-14). The Kruskal-Wallis tests indicates that the difference in yields across the three groups is statistically significant, while the post-hoc analysis by pairs (the Dunn test) indicates statistical significance in the differences between tail/middle, and tail/head sections.

Such differences are consistent with Hussain's (2005) observations in South and East Asia, noting that, against common perceptions, it was in the middle reaches − but not at the head − where productivity was the highest and poverty the lowest. In an extensive literature review, Gorantiwar and Smout (2005 p. 13) remark that 'the farmers at the head of the system generally apply more water than needed for potential yield and excess water will not improve the productivity but will reduce it'. Within the context of the ACIAR project in Tanzania, Stirzaker et al. (2017) notes that over-irrigation often results in leaching of nutrients (nitrate) from the soil.

Another critical consideration regarding farm location is the relative distance between the plot and the irrigation channel. In the logarithmic models, the distance between farm and irrigation canal is statistically significant and negatively associated with paddy yields. This suggests that farms located further away from the main canal obtain lower yields, thus reflecting the importance of heterogeneities along the distributary canals, as noted by Merrey (1997) and Mollinga (2003). This is also consistent with qualitative evidence gathered during the 2015 survey. A number or irrigators reported that, in addition to upstream/downstream issues, they experienced conflicts with 'neighbouring irrigators'. For example, one irrigator noted that:

> ‘Differences in water are not only a question of upstream/downstream, but also ‘transversal’ distance to the canal’ (female irrigator, Magozi, age not available).

5.7.3 Other variables of interest

Household characteristics including age, education and size are statistically significant across five models. By contrast with the income models, education has the expected positive sign. Gender is only significant in the models with location as dummies. The coefficient has the expected negative sign, but the results cannot be considered robust as they are not consistent across the various models.

The year dummy has a strong statistically significant influence on yields, in nine out of ten models. These quantitative results mirror qualitative explanations provided by interviewees noting that 2015 paddy production had been severely hindered by low rainfall and water scarcity within the scheme. In fact, as noted in Chapter 4, when crops are damaged or lost due to lack of irrigation water, irrigators may suffer financial losses and even consider exiting irrigation and taking up dryland farming.

Timing of water supply is statistically significant with a negative sign in three models. The interpretation of this result is that receiving water only at the end of the irrigation season is associated with lower paddy yields. As discussed in Chapter 4, late water supply affects rice production in several ways, including greater risk of crop failure and missing the optimal timing for rice cultivation. Summary statistics (Table 5-15) show that households who are supplied only at the end of the irrigation season obtain lower paddy yields, although the difference between the two groups is only statistically significant based on the Kolmogorov-Smirnov (K-S) test, but not Wilcoxon rank-sum (WRS) test (see Chapter 3). Similarities can be found in the literature with, for example, Ostrom and Gardner (1993) noting that Nepali rice irrigators at the head of the systems filled their fields with water during the pre-monsoon season, thus impeding tail-enders from cultivating water-intensive rice during that time. The importance of timing for water supplies ties in with the multiple dimensions of ‘water equity’ discussed in Chapter 6.

Table 5-13 **OLS model results of rice paddy yield in the Magozi scheme**

	Theoretical model	Backward stepwise elimination				
Independent variables	**Linear**	**Linear**	**Linear-Log**	**Log-Linear**	**Log-Log**	**Log-Linear GIS dummies**
Gender	-442.14 (313.71)	.	.	.	.	-0.29** (0.13)
Age	-27.03 (16.96)	.	.	-0.03** (0.01)	-0.03** (0.01)	-0.03*** (0.01)
Education	869.70* (509.28)	.	.	0.46** (0.19)	0.46** (0.19)	.
Household size	258.88** (116.27)	.	.	0.17** (0.07)	0.17** (0.07)	0.13* (0.07)
Irrigated area	-0.01 (0.01)	.		.		.
Ln (Irrigated area)			.		.	
Farm tools	87.31 (385.68)	.	.	.	.	.
Soil fertility	-775.37** (302.17)	.	.	-0.69** (0.26)	-0.69** (0.26)	-0.53** (0.25)
Year	-1,617.36*** (471.28)	-1,815*** (332.34)	-1,815*** (332.34)	-0.70*** (0.22)	-0.70*** (0.22)	-0.70*** (0.21)
Equity of distribution	-43.76 (185.93)	.	.	.	.	.
Satisfaction water supply	303.00 (209.28)	372.** (158.76)	372.** (158.76)	0.31** (0.13)	0.31** (0.13)	0.31** (0.13)
Timing of water (END)	-277.01 (435.30)	.	.	-0.71** (0.35)	-0.71** (0.35)	.
Distance to intake	0.04 (0.07)	.	.	.	.	
Distance to canal	-0.38 (1.19)	.	.	-0.00* (0.00)	-0.00* (0.00)	.
Tail location						-0.98*** (0.32)
Head location						-0.27** (0.13)
Herb, pest. fung.	0.01 (0.01)	.		.		.
Ln (Herb, pest. fung.)			.		.	
Constant	1,701.93 (1,300.44)	2,279*** (647.93)	2,279*** (647.93)	7.14*** (0.71)	7.14*** (0.71)	7.88*** (0.59)
Observations	98	171	171	98	98	105
R^2	0.46	0.38	0.38	0.42	0.42	0.42
Adjusted R^2	0.37	0.38	0.38	0.37	0.37	0.37
F	7.12***	63.76***	63.76***	5.85***	5.85***	6.20***

. Variables are statistically insignificant at the 0.10 level and dropped from the final model;
*** $p < 0.01$, **$p < 0.05$, *$p < 0.10$
Blanks indicate the variables are not included in the models
Standard errors in parenthesis

Table 5-13 **OLS model results of rice paddy yield in the Magozi scheme (cont')**

	Genera-to-specific				
Independent variables	**Linear**	**Linear-Log**	**Log-Linear**	**Log-Log**	**Log-Linear GIS dummies**
Gender	.	.	-0.16 (0.21)	.	-0.29** (0.13)
Age	.	.	-0.03** (0.01)	.	-0.03*** (0.01)
Education	.	.	0.42* (0.21)	.	.
Household size	.	.	0.20** (0.09)	.	0.13* (0.07)
Irrigated area	.		.		.
Ln (Irrigated area)		.		.	
Farm tools	.	.	-0.24 (0.35)	.	.
Soil fertility	.	.	-0.69** (0.28)	.	-0.53** (0.25)
Year	-1,814.99*** (332.34)	-1,814.99*** (332.34)	-0.63*** (0.22)	.	-0.70*** (0.21)
Equity of distribution	.	.	0.09 (0.10)	.	.
Satisfaction water supply	372.10** (158.76)	372.10** (158.76)	0.33** (0.14)	.	0.31** (0.13)
Timing of water (END)	.	.	-0.74** (0.35)	.	.
Distance to intake	.	.	.	.	
Distance to canal	.	.	-0.00* (0.00)	.	.
Tail location					-0.98*** (0.32)
Head location					-0.27** (0.13)
Herb, pest. fung.	.		.		.
Ln (Herb, pest. fung.)		.		.	
Constant	2,279.01*** (647.93)	2,279.01*** (647.93)	6.98*** (0.83)	7.24*** (0.15)	7.88*** (0.59)
Observations	171	171	98	98	105
R^2	0.38	0.38	0.42	0.42	0.42
Adjusted R^2	0.38	0.38	0.37	0.37	0.37
F	63.76***	63.76***	5.85***	5.85***	6.20***

. Variables are statistically insignificant at the 0.10 level and dropped from the final model;
*** p < 0.01, **p < 0.05, *p < 0.10
Blanks indicate the variables are not included in the models
Standard errors in parenthesis

Table 5-14 **Summary statistics and significance tests for paddy yields in head, middle and tail sections**

Plot location	N	Mean	Median	Std. Dev	Min	Max	Kruskal-Wallis χ^2	Dunn *p*		
Head	50	2,572	2,286	1,489	229	7,388			Middle	Tail
Middle	24	2,964	2,533	1,827	988	8,402	4.695*	Head	-0.279	1.78**
Tail	24	2,154	1,606	2,158	0	7,265		Middle		2.04**

The values are statistically significant at ** p<0.05, * p<0.1

Table 5-15 **Summary statistics and significance tests for paddy yields by timing of water supply**

Timing	N	Mean	Median	Std .Dev	Min	Max	K-S p	WRS z
Only at the end	24	2,303	1,656	2,142	0	7,265	0.105*	1.570
Any other time	74	2,650	2,286	1,625	137	8,402		

The values are statistically significant at * p<0.1

5.8 Conclusions

This chapter examines the linkages between incomes from irrigated crops and crop yields with a series of natural, physical, human, social, financial and farm management variables. Two OLS multiple regression methods are employed to test the hypotheses that incomes from irrigated crops (in Kiwere and Magozi) and crop yields (in Magozi) are positively associated with adequacy of water supply and proximity to the system's intake. Continuous variables are tested in linear and logarithmic forms, while plot locations are tested as linear distances and head/middle/end dummies.

The results of the income model fail to support the hypothesis that adequacy of water supply is associated with irrigated crop incomes, which also contrasts with previous qualitative findings in this thesis and the literature. On the other hand, the location-income hypothesis is partially supported by the negative association between (reported) tail-end location and irrigation incomes. Size of the irrigated area is statistically significant, thus highlighting the important connections between land assets and economic inequalities within agricultural communities.

The regression results of the Magozi paddy rice yield analysis maintain the hypothesis that [irrigators' perception on] adequacy of water supply is positively associated with crop yields. While using perceptions as a proxy is not without limitations (e.g. highly subjective), it could be a valuable approach for IOs to better understand water distribution within low-technology irrigation schemes − where actual deliveries cannot be empirically measured.

The strong influence of the year dummy in paddy yields suggests a connection to inter-annual variability in rainfall and water availability. One of the purposed benefits of irrigation compared to dryland is its lower risk and greater certainly of water supply. However, the fact that rice productivity in the Magozi scheme is heavily influenced by inter-annual rainfall variations raises worrying questions about the effectiveness of irrigation in insuring growers from climatic uncertainty.

Both the income and yield models suggest that proximity to the scheme intake is not statistically significant, yet tail and head location seem to have a significant negative effect. This potentially suggests that, not only water-stress is an issue for tail-enders, but also excessive water use is detrimental for head-enders. Such results call for a reconsideration of the common head vs. tail end dichotomy implying that water-location advantages are greater closer to the intake and then progressively decrease following the scheme's hydraulic gradient.

The statistical significance of human and household characteristics, such as age of the head and family size, suggest that policies targeting social aspects of irrigation development could potentially influence the positive outcomes of irrigation. Nevertheless, these linkages should be considered in further depth. For example, the fact that larger family sizes are positively associated with irrigated crop incomes and yields, could be a result of the contribution of children to farm labour.

Chapter 6 A review of Tanzania's policies on equity of irrigation water supply

6.1 Chapter objectives

Previous chapters in this thesis have identified significant water supply inequities within two smallholder irrigation schemes in Tanzania. The findings indicate that such imbalances at the local scale may have deep repercussions on various aspects of irrigators' wellbeing, including economic inequalities, social power relationships, conflict, crop yield and risk of crop failure, amongst others. Several national water and irrigation policies in Tanzania (The United Republic of Tanzania 2002, 2013a) set equity of water supply as a key priority, although its definition remains somehow ambiguous, as explained in Section 6.5.5. Moreover, strong water supply heterogeneities within traditional schemes raise the question as to whether the equity goal has been actually achieved at small scales. The main objective of this chapter is to understand the reasons why Tanzanian polices have apparently failed to achieve equity of water supply within traditional irrigation schemes and to propose possible policy options. The data used in this chapter was collected through desktop policy research, as well as personal interviews with members of the IOs and government staff (see Section 2.4.4 for details).

The first sections of this chapter provide a literature review and the definition of a new analytical framework for the study of equity of irrigation water supply. Then, Tanzania's water and irrigation governing polices and authorities are examined. Finally, drawing from the case of the Kiwere and Magozi schemes, a discussion provides insights into the advantages and disadvantages of potential interventions to improve equity of water distribution.

6.2 Introduction

Equity of water distribution is recognised as a top priority for water resources management (Kolberg 2012; Wegerich 2007) and is commonly among the key goals of public water polices (Peña 2011). Social equity stands as one of the three pillars of IWRM, together with economic efficiency, environmental sustainability. Within the context of IWRM, equity is defined as 'The basic right for all people to have access to water of adequate quantity and quality for the sustenance of human wellbeing' (Global Water Partnership 2000 p. 30). Access to adequate domestic water supply is critical to sustain life and health, while access to water for productive uses (such as irrigation) is key to support incomes and development. Equitable access to irrigation water becomes particularly critical in rural areas of developing countries, where large parts of the population depend on agriculture as their main source of livelihoods. As Turner et al. (2004) highlight:

> In an inappropriate environment, e.g. where land is not evenly distributed, economic benefits of irrigation may be received predominantly by wealthy farmers and reinforce inequalities in the distribution of resources and wealth. The policy and institutional environments play critical roles in determining whether irrigation has positive impacts for poor people (p. 8).

The United Republic of Tanzania is a valuable case study to investigate inequalities in irrigation water supply. Agriculture is the dominant economic sector in Tanzania, accounting for almost one-third of the GDP and providing employment for three-quarters of its more than 50 million citizens (Mashindano et al. 2011). At a national level, irrigation is considered a key strategy to increase incomes and food security in rural areas, given its potential for higher crop yields and lesser hydro-climatic risk than rainfed agriculture (The United Republic of Tanzania 2014a).

Following legislative reforms in the early 2000s, Tanzania has developed a number of water and irrigation national policies calling for improved water management through the adoption of IWRM plans. Nevertheless, there is evidence suggesting that such polices have not yet been successful in achieving adequate water distribution. Previous studies have highlighted the shortcomings of the Tanzanian legislative reforms at the scale of river basins and catchments (van Koppen et al. 2004; van Koppen et al. 2007). Adding to the existing literature, this chapter examines Tanzania's policies at local scale (e.g. within smallholder irrigation systems) focusing on equity of irrigation water supply. Filling this policy and knowledge gap is particularly important because it is in the local context where possible water management and social equity solutions may be firmly grounded (Peña 2011).

6.3 Literature review

6.3.1 The compromise between equity and efficiency of irrigation systems

The trade-off between equity and efficiency is a longstanding topic of discussion in welfare economics (Berg & Ostry 2011; Bourguignon et al. 2007; Browning & Johnson 1984; Okun 1975). Similarly, within the context of irrigation, equity and efficiency[7] are two fundamental water management goals (Lal Kalu et al. 1995; Sampath 1988; Steiner & Walter 1992), although in resource-scarcity situations, polices targeting one objective will typically fail to achieve the other. As Lal Kalu et al. (1995) explains:

> [in] most surface irrigation systems, particularly in developing countries, (…) the distribution canals are generally earthen and in delivering water to distant fields a substantial quantity of water is lost due to seepage. In such situations, if the water delivery is limited to fields in upper reaches alone, more water can be used efficiently by reducing conveyance losses, but such a distribution will not be equitable (p.336).

Finding the optimal compromise between equity and efficiency remains a complex task, as the balance depends on varying climatic circumstances, water availability, demands and individual preferences. Field lab experiments in Tanzania on the trade-offs between equity and efficiency (D'Exelle et al. 2012; Lecoutere et al. 2015) show that irrigators predominantly choose rules favouring water equity. However, self-benefiting, water-efficient behaviours became more frequent under water scarcity scenarios.

Adequate policies and institutional environments play critical roles in determining the positive impacts of irrigation (Turner et al. 2004), including equity and efficiency. Tisdell (2003) suggests that when institutional structures concentrate on ensuring efficient use of available resources, social equity can be achieved through other avenues, such as welfare programs and taxation. An example of this type of policy is the Private Irrigation Infrastructure Operators Program in New South Wales, Australia (Australian Government 2016), which targeted high

[7] Discussions in this chapter focus on conveyance efficiency, which can be defined as 'the ratio of the amount of water delivered at the turnouts of the main irrigation conveyance network to the total amount of water diverted into the irrigation system' (Small & Rimal 1996 p. 26).

water efficiency within private irrigation schemes. Under certain circumstances, and among other strategies, the program supported water loss reduction through the permanent shut-down of tail end sections of open-channel systems. In exchange for fallowing their land, affected irrigators were offered a series of compensation measures, such as cash or relocation.

While such initiatives may be effective and economically viable within large-scale irrigation schemes in developed countries like Australia, welfare and taxation interventions, as suggested by Tisdell (2003), remain widely unavailable for smallholder irrigators in many parts of the developing world. Thus, a large body of literature advocates for government institutions and public policies targeting greater equity of water distribution. Syme et al. (1999 p. 52) note that 'Government policies constantly state that resources will be allocated equitably', while Boelens and Dávila (1998 p. 201) point out that 'the theme of irrigation and equitable water distributions is one of the most important agrarian issues in various Andean countries'. Similarly, Makombe and Sampath (1998) indicate that equitable distribution of irrigation resources is a central policy objective for the government of Zimbabwe. Drawing from Mexican *unidades de riego*, Dayton-Johnson (1999) notes that a fundamental task of any irrigation group is establishing water allocation rules, while Anwar and Ul Haq (2013) explain that a key objective of Pakistan's *warabandi* system of irrigation management is to provide equitable water distribution.

6.3.2 Geographical scales: macro, meso and micro scales

Hussain and Hanjra (2004) developed a framework for policy and intervention analysis consisting of three spatially-defined levels (macro, meso and micro) through which access to irrigation water may impact socioeconomic factors in rural communities. This approach has been subsequently applied in the study of: a) the irrigation-poverty nexus (Hussain 2005); b) the value of agricultural water (Hussain et al. 2007); c) irrigation water equity policies (Kolberg 2012); and d) agricultural water efficiency (FAO 2015a).

Geographically speaking, the macro, meso and micro levels of water management may correspond, respectively, to national, regional and local extents. The three levels (also referred to as pathways) are interlinked and influence each other, yet their objectives are very distinct (Table 6-1). The macro/national level aims to define overarching policies promoting countrywide growth, sustainability, food security and derived benefits from irrigation. The goal of the meso/regional level is to achieve territorially and socially equitable allocation of water and to reduce conflicts among competing uses (Kolberg 2012). The micro/local level is centred on households, farms and communities and aims to improve welfare (chiefly of poor households) through greater crop production and incomes from irrigation.

Table 6-1 **Macro, meso and micro levels of irrigation water management**

Levels	Geographic extent	Actors	Objectives related to equity of water supply
Macro	Country	National institutions	Development of water policies, laws and regulations Socioeconomic welfare and food security
Meso	Region, Basin	Regional institutions	Equitable water allocation and conflict resolution among users Derived benefits (e.g. labour, markets, stakeholder profit)
Micro	Community, Irrigation system	Farms and households	Water efficiency and crop productivity Optimal allocation of productive resources Increased returns to poor households and risk minimisation

Source: Adapted from Hussain and Hanjra (2004), Hussain et al. (2007) and Kolberg (2012).

6.3.3 Irrigation systems as Common Pool Resources

Irrigation systems are often conceptualised as a common pool resources (CPRs), which are defined as man-made or naturally occurring resources where exclusion is difficult and yield is substractable (Ostrom & Gardner 1993). The first attribute means that it is difficult or very costly to exclude outsiders from accessing the resource, for example enforcing property rights or fencing of the resource. Thus, strong institutional arrangements are required to stop (or at least reduce) free-riding use of the resource. The second concept – substractabilty – refers to the appropriation of the resource, whereby the amount withdrawn by one user (e.g irrigation water from the canals) is no longer available to others.

Like other CPRs, irrigation systems face two distinct collective action problems: provision and appropriation (Janssen et al. 2011). Provision issues are related to the time-dependent, productive nature of investment and may include problems in construction and operation and maintenance (O&M) of the irrigation infrastructure (Jing et al. 2010; Ostrom 1990). Appropriation problems concern the allocation of resource units among its users in a manner that is fixed and time-independent. In limited-access CPRs, users' incentives depend on rules regulating quantity, timing, location and technology of appropriation and how these are monitored and enforced. Spatial heterogeneities in access to the resource can be a major appropriation problem, for example, the relative position of head-enders and tail-enders in gravity-fed, irrigation systems

(Ostrom & Gardner 1993). When resource users are dissatisfied with the allocation of access rights and obligations (e.g. they perceive it as unfair or uncertain), their willingness to invest in provision activities (e.g. maintenance) may be adversely affected (Ostrom 1990). Then, if existing rules are not adequately enforced, there is even greater tendency for water users to avoid contribution of labour or fees to the system. Increasing water-use fees has been proposed as a way to increase agricultural production and wealth equality among smallholders in Pakistan (Bell et al. 2016), whereas evidence in Tanzania (van Koppen et al. 2007) shows that enforcing payment on small water users is an ineffective water management strategy.

It has been argued that asymmetries between upstream/downstream users of large-scale irrigation systems require a central authority to solve collaboration problems (Janssen et al. 2011). Indeed, there is evidence that some government-managed schemes outperform those run by farmers and other cases where external intervention is indispensable to carry out complex civil works (Lam 2006). On the other hand, there are many cases where farmers successfully govern complex irrigation systems without external control (Joshi et al. 1998; Lam 1996). In these systems, external rules can be perceived as impositions to be worked around rather than worked by (Lam 1996). Thus, rather than questioning whether irrigations systems should be government or farmer-managed, the broader theory (Lam 2006) suggests that a more relevant question is what are the optimal institutions for sustaining collaboration between farmers and managers.

Regardless of the degree of government intervention, the sustainability of traditional irrigation systems largely depends on individuals' ability and willingness to cooperate with one another respecting water sharing rules and contributing to O&M of the infrastructure. Drawing from extensive observations of CPRs across the world (e.g. California, Spain, Nepal, Philippines, etc.), Ostrom (1990) identified eight key design principles used by those who are able to successfully manage their CPRs over extended periods of time. Within the context of irrigation (Ostrom 1992, 1993), these principles can be summarised as follows:

1. Clearly defined boundaries of the irrigation systems and of the individuals who have rights to withdrawal from it
2. Equivalence between benefits and costs, whereby water allocation is related to individuals' contributions (labour, materials or money). This is also referred to as congruence between appropriation/provision rules and local conditions.
3. Collective choice arrangements that allow individuals affected by rules to be part of the group who can modify these rules.
4. Monitoring of behaviours conducted by irrigators themselves or by monitors who are accountable to irrigators
5. Graduated Sanctions applied upon breakage of rules that are proportional to the gravity of the offence or to other agreed criteria.
6. Conflict resolution mechanisms that are low-cost and accessible to irrigators within their local environments
7. Minimal recognition of rights to organise, whereby irrigators' institutions are not challenged by external authorities.
8. Nested enterprises at multiple layers that manage actives regarding appropriation, provision, monitoring, enforcement, conflict resolution and governance of the irrigation system.

Ostrom's original work (1990) is cited thousands of times in the literature and her CPRs design-principles are widely discussed in subsequent studies (Deininger 1996; Jing et al. 2010; Lam 1996; Ostrom & Benjamin 1993; Pasaribu & Routray 2005; Quinn et al. 2007). More specifically, Dietz et al. (2003) add to Ostrom's initial framework, by pointing out conditions under which effective governance of CPRs is more easily achieved. These include situations when (i) resources and their use can be monitored in a low-cost, transparent manner; (ii) rates of change in resources and populations are moderate; (iii) members of the communities maintain close relationships; (iv) outsiders can be excluded; and (v) users support effective monitoring and rule enforcement.

Despite the general optimism surrounding CPRs design principles, Campbell et al. (2001) raise concerns about their applicability and success in sub-Saharan Africa, particularly in Zimbabwe. The authors argue that greater clarity is needed to understand nuances between different types of boundaries (e.g. natural and administrative) and community members (e.g. users and stakeholders). In a study of 38 CPRs systems in 12 Tanzanian villages, Quinn et al. (2007) found that Ostrom's eight design principles were often weak or absent, chiefly those regarding boundaries, monitoring and conflict resolution. Indeed, the political administration units created in Tanzania do not relate to the natural boundaries, thus creating an institutional overlap.

6.3.4 Water Poverty Index

The Water Poverty Index (WPI) (Sullivan 2002) is a holistic tool to measure various aspects of water stress that provides a consistent methodology applicable at large and small scales. The goal of the WPI is to serve governments and policy makers across the world in the identification and prioritisation of interventions towards improved water access. Furthermore, the WPI establishes a parallelism between water and socio-economic poverty, thus allowing to investigate linkages between the various dimensions of poverty (Kaczan & Ward 2011).

The original index (Sullivan 2002) is focused on domestic water supply and accounts for water availability, access to safe water/sanitation and time required to fetch water. The WPI was initially defined on a 0-100 scale as a simple and easy to understand tool. Since its creation, numerous studies have revisited the WPI to propose new definitions addressing some of the initial weaknesses. For example, Sullivan et al. (2003) add to their initial work by addressing water quality, variability, management, as well as water for non-domestic uses such as food production and environmental sustainability. Further to this, Sullivan et al. (2006) formally redefine the WPI as a weighted average of five components: resources, access, capacity, use and environment.

Subsequently, Pérez-Foguet and Giné Garriga (2011) define the enhanced WPI (eWPI) combining physical, environmental and social dimensions influencing sustainable development of water resources. Incorporating quantitative and qualitative data, Wilk and Jonsson (2013) elaborate the WPI^+ , where higher scores represent water prosperity rather than poverty. Along a similar line, Jemmali and Abu-Ghunmi (2016) propose the modified WPI (*m*WPI) by applying an additive aggregation function to scores from nine indicators: availability, variability, access, domestic use, economic capacity, physical capacity, social capacity, institutional capacity and water quality. Forouzani and Karami (2011) conceptualise the Agricultural WPI (AWPI) by synthesising relevant water-poverty aspects for agricultural use and list 31 indicators (e.g. river water withdrawals, farm location, crop productivity, education, pesticide use, etc.) that are classified into the five concepts proposed by Sullivan et al. (2006). A valuable feature of the AWPI is that, in addition to quantities, it incorporates many other critical factors such as land failure due to water scarcity, farmers' level of education in water management, land levelling and conflict occurrence. The work, however, remains highly theoretical without an empirical formulation applicable to irrigation water poverty. Indeed, many of the proposed indicators (e.g. Productivity of water: income from the crop × per ha per year divided by total water volume used for irrigation per ha) would be very difficult to calculate given the limitations of data availability within smallholder irrigation schemes.

The WPI has been criticised for being subject to distortion due to inadequate data (Komnenic et al. 2009) and for overlooking the in-depth, complex causes of water depravation (Molle & Mollinga 2003). Indeed, the causes and solutions for water scarcity may rise from multiple sources, including physical, economic, managerial, institutional and political constraints (Ibid.). Similar to the poverty line, the headcount index and the poverty gap, the WPI is useful for poverty comparisons *between* populations. However, as an aggregate measure, the WPI does not provide any information on disparities *within* the populations of study (e.g. country, region or community).

Within the context of urban water supply and sanitation, the UN (2013a) propose the use of 'The Equitable Access Score-card' – a country-wide, self-evaluation tool aimed at measuring access disparities between regions and social groups. The method for analysis comprises multiple aspects such as rights and obligations of users, affordability, policy, education, physical access and quality of the service. No similar framework exists at the international or national levels to evaluate equity of access to irrigation water supply in such a comprehensive, systematic manner.

6.4 A framework for the analysis of equity of irrigation water supply

In the study of economic and resource inequalities, an important and recurrent question is: equality of what? (Sen 1979). The most obvious measure of equity of water distribution is in relation to the quantity of water supplied, whether it is measured in terms of volumes (El-awad et al. 1991); flow (Bos et al. 1991); or allocated time (Malhotra et al. 1984). In addition, many other aspects of equity exist, with several authors calling for considerations on obligations, decisions-making, reliability, and cost, among others. Approaches from different authors share certain similarities (Table 6-2), but there is a no consistent framework for the evaluation of the various aspects of equity of water irrigation distribution. Given the current methodological gap, a new framework for the analysis of equity of irrigation water distribution in this chapter is proposed (Figure 6-1).

Table 6-2 **Literature review of irrigation water distribution equity aspects**

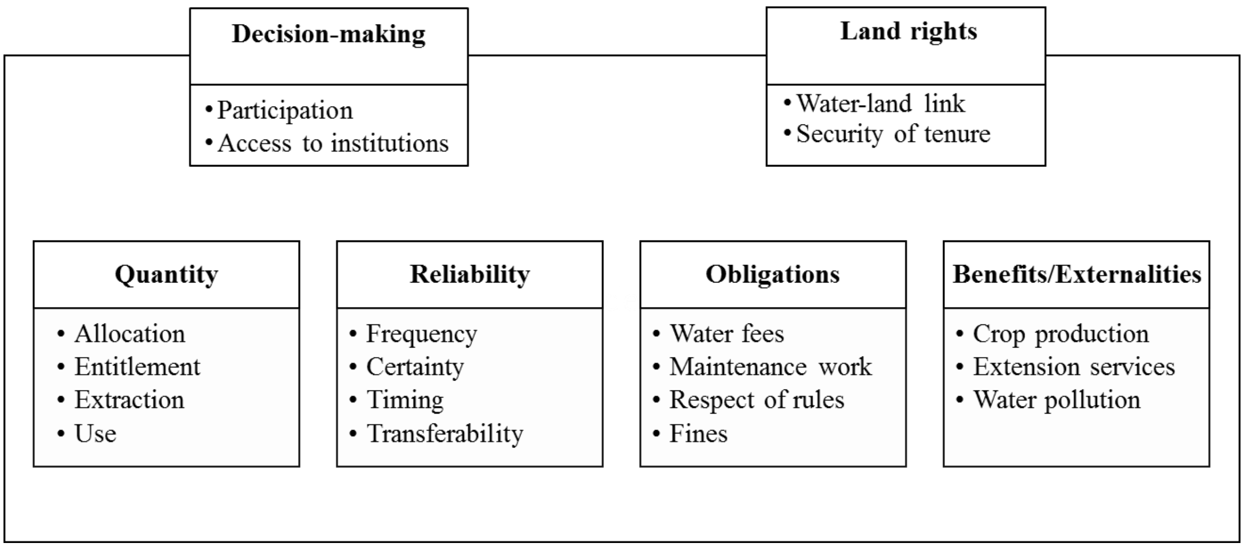
Equity aspects of irrigation water distribution	Source
Benefits (water and land); and responsibilities	Hussein et al. (1987)
Quantity; labour contributed to maintenance; capital investment; land owned	Ostrom and Benjamin (1993)
Participation in decision-making; costs; benefits (income) water quality; allocation; environmental impact; sustainability	Syme and Nancarrow (1997)
Allocation; reliability and timeliness	Joshi et al. (1998)
Contributions; obligations; and amounts of water	van Etten et al. (2002)
Flexibility and rigidity to change water rights; certainty; security of tenure; transferability; allowance for in-stream water rights; and externalities resulting from trade.	Tisdell (2003)
Quantities; timing; water markets; pricing; decision-making institutions; access to inputs (land credit, seeds, fertiliser); externalities (heath and environment)	Lipton et al. (2003)
Water distribution and allocation; services involved in irrigation development; added agricultural production and other benefits under irrigation; burdens and obligations related to functions and positions; and rights to participate in the decision-making process	Cremers et al. (2005)
Access (entitlement, accessibility, affordability); socio-economic impacts; extent of use; and cost	Prasad et al. (2006)
Spatial; Social; Gender and Inter-generational equity	Phansalkar (2007)
Social equity (decision-making processes); practice of water resources management (extraction and discharges); and water-related services (obtaining benefits from water)	Peña (2011)
Water rights; decision-making; resource contribution to maintenance work; water allocation; amount of water actually distributed; information sharing; and conflict resolution	Wong and Herath (2014)
Irrigation infrastructure; timeliness of supply; water distribution/allocation; equitability of supply; other important factors	Mdemu et al. (2017)

The first step in defining the framework was to compile a comprehensive list of all water equity aspects found in the literature (Table 6-2). Many aspects across various studies referred to the same concepts, although in some cases, synonyms or slightly different terms were used. For example, Wong and Herath (2014) use 'water allocation' and 'amount of water actually distributed', while Cremers et al. (2005) refer to 'water distribution and allocation'. Second, for the purpose of clarity and consistency, similar or synonym terms were merged into a shorter, more concise list of equity aspects. Then, equity aspects were grouped into common themes, which resulted in six main categories: 1) quantity; 2) reliability; 3) obligations; 4) benefits/externalities; 5) decision-making; and 6) land rights (Figure 1). Decision-making and land rights are set as overarching terms applying to all of the other four equity aspects. In fact, equity of 'decision-making' - as noted by previous studies - is not well defined *per se*, but it needs to specify what exactly is being decided. For instance, the local institution governing an irrigation system may have equity of decision making regarding water allocations, yet decision-making on fees and repair work may be unilaterally decided by an external agent. Likewise, land property rights is fundamental for irrigators' water equity, particularly in situations where water allocations and obligations are established proportional to land size. Also, for irrigators who do not own but rent land, securing land access from one season to another provides them with greater reliability to plan their irrigation investments. Thus, within the context of equity of irrigation water supply, the following definitions are proposed:

- *Quantity* refers to the amount of water that is distributed among water users, whether it is measured in terms of volume, depth, time or other quantitative proxy indicators. Water quantity can refer to allocation, entitlement, extraction or actual water use.
- *Reliability* refers to the characteristics of water access that make it more (or less) secure for water users. These include: frequency, certainty and flexibility of supply; adequacy of timing to meet cropping calendar; security of tenure of water rights; and transferability of water rights.
- *Obligations* refer to the mandatory contributions that water users must make towards the common system. These include, for instance, respect of water-sharing rules, routine and deferred maintenance, water fees and additional contributions (e.g. cost of repairs).
- *Benefits/Externalities.* Benefits derived from access to irrigation water may include crop production, incomes and access to development services (e.g. extension, subsidies, credits, market value-chain and training). Negative externalities refer to the undesirable impacts on other water users (e.g. worsened water quality) or the environment (e.g. depletion of natural resource, soil erosion or pollution).

- *Decision-making* refers to the ability of irrigators to participate and influence processes that determine the distribution of quantity, reliability, obligations and benefits/externalities related to water supply. 'Equity of decision-making' encompasses irrigators' access to water-governing institutions, participation in meetings and acceptance of their options by their peers and leaders.
- *Land rights* refers to irrigators' ability to own or rent land within the irrigation scheme and have this right recognised by the relevant institutions.

Figure 6-1 **Framework for the analysis of equity of irrigation water distribution**



Source: Author's synthesis from literature and fieldwork

The framework for analysis of equity of irrigation water distribution can be compared to Ostrom's CPRs and the Water Poverty Index. While they differ in the main question of analysis, there is a certain correspondence between the concepts in each of the three frameworks (Table 6-3).

The water equity framework serves to define all aspects that are relevant for equity of water distribution. By contrast, Ostrom's CPRs work addresses the institutional set up of irrigation schemes to define desirable governance principles. Another difference resides in the appropriation problem, which is concerned with fixed or time-independent resource allocation (Ostrom 1990). As discussed in Section 6.3.1, water allocations within an irrigation scheme cannot be fixed, as the optimal compromise between efficiency and equity change with water availability – a highly time-dependent factor.

Ostrom's CPRs design principles on governance of the resources are aligned with decision-making and the institutional set up of irrigation schemes, while land rights reflects the principle of clearly defined boundaries (access to the CPR). Equity of quantity, reliability and externalities are associated with monitoring, as it is fundamental to measuring and evaluating these three objectives. Proportional equivalence between benefits and costs and graduated sanctions are related to irrigators' obligations to contribute to scheme maintenance, respect rules and pay fines according to the established punitive system.

In the WPI framework, capacity is defined as the users' ability to manage the water resources, thus corresponding to decision-making and obligations. Access to irrigation water is associated with access to land within the scheme and also the security of supply (reliability). Resources (water available) and use refer to quantities of water, while environment relates to the impact of water on the ecosystem (externalities).

Table 6-3 **Comparison of frameworks for the analysis of water management**

Equity of irrigation water distribution	**Ostrom's CPRs design principles**	**Water Poverty Index**
Decision-making	Collective choice arrangements Conflict resolution Minimal recognition of rights to organise Nested enterprises	Capacity
Land rights	Clearly defined boundaries	Access
Quantity	Monitoring	Resources Use
Reliability	Monitoring	Access
Obligations	Graduated Sanctions Equivalence between benefits and costs	Capacity
Benefits/Externalities	Monitoring	Environment

6.5 Water and irrigation legislative authorities in Tanzania

6.5.1 From centralised to decentralised water policies

Over the last decades, management of natural resources in Tanzania, as in other sub-Saharan countries, has undergone a significant transformation from a centralised to a decentralised system. During pre-colonial times, natural resources were governed by informal rules, which were subject to changes following interactions among various population groups (Sokile et al. 2003). Formal water law in Tanzania dates back to the early 1900s, when it was first introduced by German and British settlers as a way to grant water rights for agricultural development (van Koppen et al. 2004). By the 1950s, management of water and other natural resources was controlled by the colonial government. Quinn et al. (2003) argue that resource management imposed by central legislation was unsuccessful for a number of reasons, such as not accounting for biophysical and human heterogeneities at the local level. Following independence in 1961, the political focus was on strengthening the country's unity. Accordingly, water remained under the control of the newly created United Republic of Tanzania (van Koppen et al. 2004). Principal water officers and regional officers – to be appointed by the Minister – are first mentioned in the *Water Ordinance* of 1959 and, successively, in the *Water Utilization (Control and Regulation) Act* of 1974.

Irrigation development in the 1960s focused on building large schemes for commercial and food security purposes, which were managed by state agencies and employed paid farmers (Mdemu et al. 2017). During the 1970s, rural water supply remained strongly controlled by the central government following its promise to cover capital, operation and maintenance costs (Mashauri & Katko 1993). By the late 1980s, many of the large irrigation schemes had developed significant issues such as high O&M costs, poor performance and negative environmental impacts, which became unbearable for governments and donors (Diemer & Vincent 1992). As a result, the attention started shifting towards a greater participation of regional and local stakeholders and thus, some schemes were privatised and others handed over to small-scale farmers.

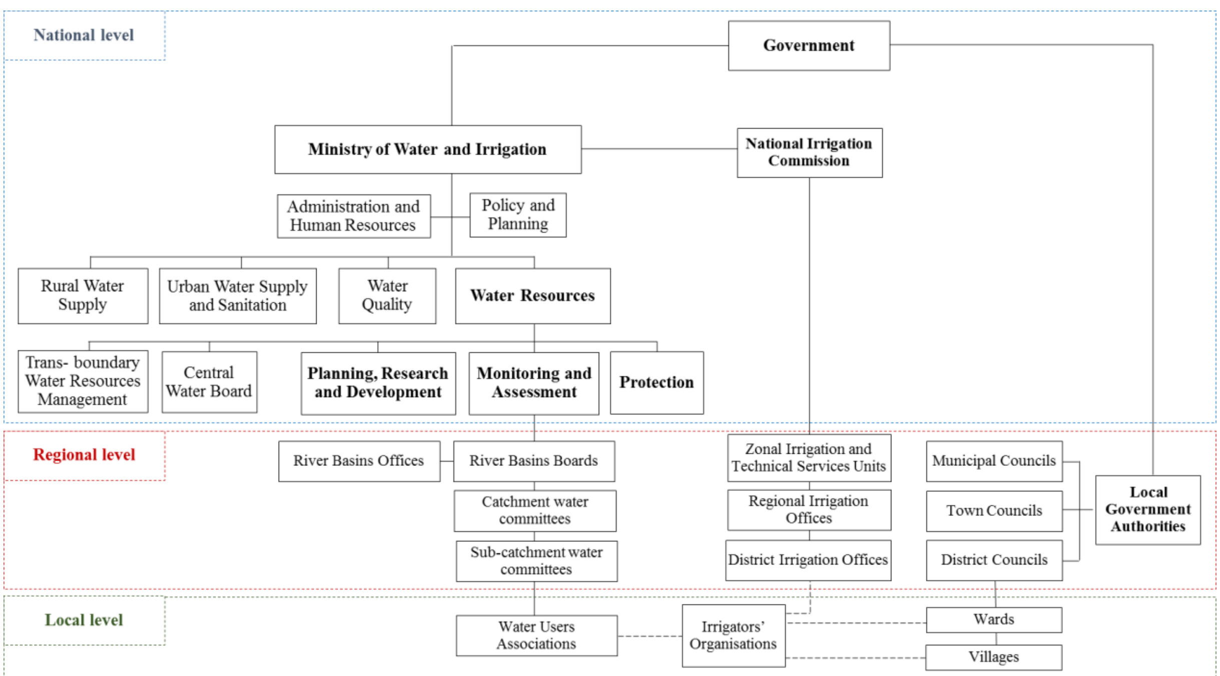
From 1981 onwards, basin boundaries were introduced to gradually replace regions as the first sub-level under the national authority (van Koppen et al. 2004). During the 1990s, the Tanzanian government amended the national water rights system and commenced a comprehensive reform which resulted in the current water and irrigation policies structured upon decentralised authority systems. This shift was introduced in line with *Agenda 21* of the United Nations Environment Meeting held in Rio de Janeiro in 1992, emphasising the subsidiarity principle, whereby water should be managed at the lowest appropriate level (The United Republic of Tanzania 2006). A key aim of the reforms was to collect fees and taxes from water users to cover a) acquisition of 'water rights' and b) infrastructure O&M (van Koppen et al. 2004). Another paramount strategy of the reforms was to adopt IWRM, which included objectives such as increased water-use efficiency, crop productivity and equity of water supply.

Van Koppen et al. (2007) claim that the Tanzanian water reforms of the early 2000s failed to achieve two of their main objectives: cost-recovery and improved water management to alleviate water scarcity issues at a basin level. The authors argue that major weaknesses in the reform process included lack of scientific analysis and poor stakeholder consultation.

6.5.2 Tanzania's water-governing bodies

Following the decentralisation process, Tanzania's water governing authorities are currently structured on five levels of resources management: i) national; ii) basin; iii) catchment; iv) district; and v) community (The United Republic of Tanzania 2002). In accordance with the three-tier geographical framework of institutional water analysis (Section 6.3.2), national level is at the top; basin, catchment and district divisions fall within the regional level and community corresponds to the local level. A schematic representation of the institutional mapping is shown Figure 6-2, while a summary of roles and responsibilities of the main institutions is provided at the end of this section in Table 6-4.

Figure 6-2 **Water and irrigation institutional mapping of Tanzania**



Source: Author's synthesis from legislative documentation

National level

At the national level, the Ministry of Water and Irrigation is Tanzania's uppermost authority governing water resources. In December 2005, the Ministry of Water – holding urban supply, sanitation and irrigation competencies − was formed following the dissolution of the former Ministry of Water and Livestock Development; and the Ministry of Agriculture, Food, Security and Co-operatives. In 2010, irrigation was transferred to the Ministry of Agriculture, only to be brought back in 2015 to the current Ministry of Water and Irrigation (MoWI). Currently, the MoWI is responsible for the formulation and revision of the *National Water Policy*, policy implementation strategies and other regulations (The United Republic of Tanzania 2014b). In 2013, the *National Irrigation Act* established the National Irrigation Commission (NIC) as an independent department under the Ministry responsible for irrigation. The NIC is responsible for the coordination, promotion and regulation of the irrigation sector and shall nominate offices to delegate its functions at regional levels.

The *National Water Policy 2002* is Tanzania's primary legislation governing water resources management, replacing the previous 1991 policy (WREM International 2015). The *National Water Policy* establishes priorities in water resources allocation where human needs come first, followed by environmental uses second and economic uses third. Among the latter, irrigation is prioritised as a way of reducing poverty and enhancing food security (Mdemu et al. 2017). Key objectives include: equity in resource allocation; efficiency in resource utilisation; water quality management; environmental and ecosystem protection and conservation; stakeholder engagement; institutional strengthening; and financial sustainability. Other national polices and strategies addressing equity of water supply are *National Water Policy 2002*, *Water Sector Development Strategy 2006*, *Water Resources Management Act 2009*, *National Irrigation Policy 2010* and *National Irrigation Act 2013* (further details on the equity aspects of each of these policies are provided in Appendix G).

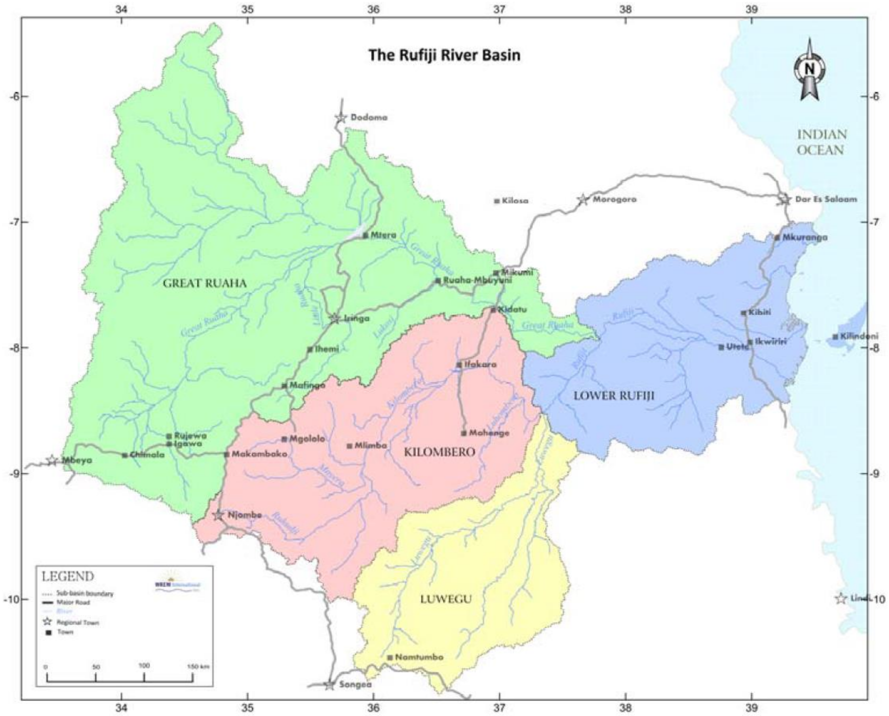
Regional level

The Basin Water Boards (BWBs) occupy the second level of water management authority in Tanzania, under the MoWI, which shall provide them with strategic guidance, technical and operational support. There are nine BWBs, one for each of the country's major river basins (The United Republic of Tanzania 2014b). Members of the BWBs are appointed by the Minister of Water and Irrigation and drawn from public institutions and the private sector. BWBs do not hold political power and their primary responsibilities are to allocate water resources, control water pollution and protect water sources. BWBs delegate their executive functions to Basin Water Offices (BWOs), who undertake resource management tasks and report to BWBs.

The area of study in this thesis falls within the jurisdiction of the Rufiji Basin Water Board (RBWB). The RBWB comprises ten members and delegates its executive functions to the Rufiji Basin Water Office (RBWO). The head of the RBWO is a Water Officer who reports to the RBWB, of which he/she is also a secretary (IATI 2014). The RBWO has its headquarters in Iringa Municipal Town and carries out day-to-day duties related to management of water resources in the Rufiji Basin. In November 2015, the RBWO completed its Integrated Water Resources Management and Development (IWRMD) plan (WREM International 2015), the implementation of which is subject to funding availability.

The Rufiji Basin covers an area equivalent to 20 percent of Tanzanian's land comprising four distinct river catchments: Great Ruaha, Kilombero, Luwegu and Lower Rufiji (Figure 6-3). The Great Ruaha - where the Kiwere and Magozi schemes are located - is the largest sub-catchment of the Rufiji Basin (85,554 km^2), accounting for 80 percent of the basin's consumptive water uses (WREM International 2015). The Great Ruaha Catchment Committee and two sub-catchment committees were formed after the launch of the IWRMD plan and are currently working on the definition of their own plans and by-laws.

Figure 6-3 **Map of the Rufiji Basin**



Source: WREM International (2015)

Catchment and sub-catchment water committees (CWCs) in Tanzania are being developed in accordance with the decentralisation strategy of the *National Water Policy 2002*. In the meantime, District Facilitation Teams (DFTs) cover IWRM activities at district and lower government levels, including capacity building of WUA and conflict resolution. A number of DFTs were created in the late 1990s, some of which still remain active amid a continuous transformation of catchment and district legislative structures. However, because the basins, catchments and sub-catchments follow natural boundaries, they do not coincide with Tanzania's administrative divisions (see Rufiji Basin area in Figure 6-4).

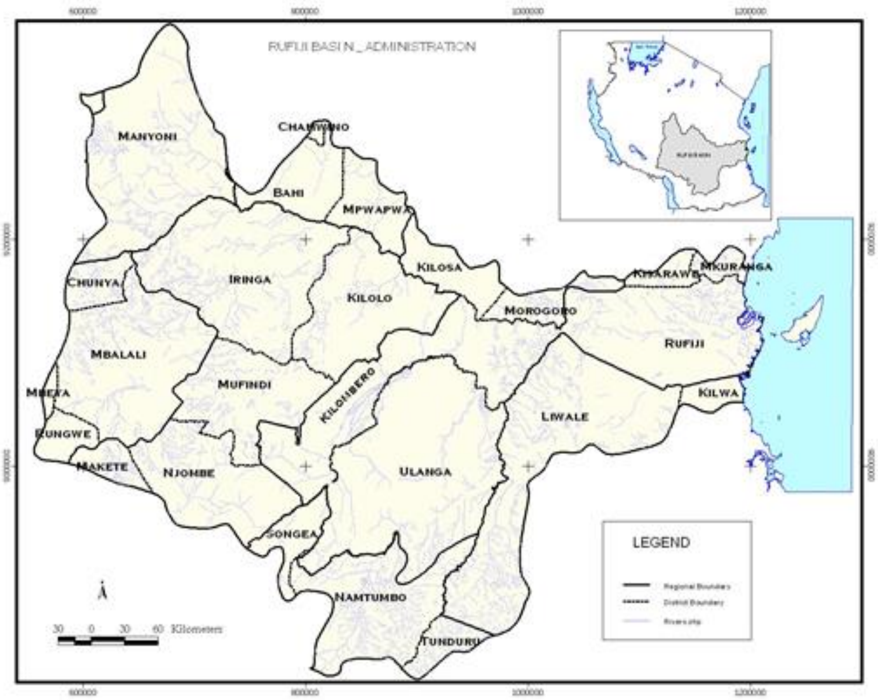
As part of the wave of institutional reforms launched in the 1990s, Tanzania's Local Government Reform Program (LGRP) was rolled out between 1998 and 2008, with the aim of transferring resources and competences from the central to local government (Kessy & McCourt 2010; Tidemand & Msami 2010). Subsequently, a second phase, LGRP II (2009-2014) was carried out continue the decentralisation efforts and improve access and quality of services provided by Local Government Authorities (LGAs) (Kessy & McCourt 2010; The United Republic of Tanzania 2012).

Under the national government, mainland Tanzania is divided into 26 regions, which are further sub-divided into 177 LGAs, also known as councils. Councils are classified as follows: 137 district councils (rural); 16 municipal councils (urban); and 24 town councils (urban) (The United Republic of Tanzania 2017). The District Councils (DCs) cover rural areas and bear certain competencies in irrigation development such as: identification, selection and planning of schemes for development; procurement of services and mobilisation of funds; and provision of assistance to establish and strengthen IOs (The United Republic of Tanzania 2010). For instance, over the past few years in Magozi, the District Council has provided funding for infrastructure maintenance, facilitated training on rice production and delivered rice-processing machinery.

Under the Agricultural Sector Development Program (ASDP), DCs are eligible to apply for funding grants from the central government (Tanzania 2006). Elected district administrators have the discretionary budget and power to authorise irrigation infrastructure works, although they have no control over the water resources. DCs do not receive orders from RBOs and their points of interaction are based on specific projects or interventions. For instance, Districts Councils are supposed to seek water permits for developments from the RBOs, who have the competency to approve or reject such requests. For example, in 2013 ANU project staff witnessed a situation where an irrigation scheme was being built with funds and approval from the Mbarali District Council, yet the RBWO denied the approval of the requested water licence (personal communication, James Pittock, 16/06/2017).

Besides BWBs and LGAs, other irrigation-governing institutions exists at the regional level under the NIC. The NIC delegates its executive functions into Zonal Irrigation and Technical Services Units (ZITSUs), each comprising three or four Regional Irrigation Offices (RIOs), which then trickle-down into several District Irrigation Offices (DIOs). ZITSUs serve to provide LGAs, IOs and the private sector with technical support regarding: design, construction and supervision of irrigation infrastructure; preparation of tender documents; capacity building, construction and technical services (The United Republic of Tanzania 2010). ZITSUs may also collaborate with BWOs to promote IWRM in the basis.

Figure 6-4 **Administrative boundaries of the districts within the Rufiji River Basin**



Source: UDSM (2017)

Local level

The Water User Associations (WUAs) – also referred to as Water User Groups (WUGs) − are the lowest level of water management in Tanzania (Kashaigili et al. 2005). WUAs may be formed by (but not limited to): Irrigators’ Organisation (IOs); domestic water users; livestock keepers; fisheries; or a combination of the above groups. According to the *Water Management Act 2009* (The United Republic of Tanzania 2009b):

> A Water User Association may be formed by the agreement of the majority of a group of water users for one or a combination of the following purposes: (a) manage, distribute and conserve water from a source used jointly by the members of the water users association; (b) acquire and operate any permit under the provisions of the Water Act; (c) resolve conflicts between members of the association related to the joint use of a water resource; (d) collect water user fees on behalf of the Basin Water Board; and (e) represent the special interests and values arising from water used for a public purpose (…). (p. 397)

Overall, WUAs are responsible for local level management of issues related to their allocated water resources. Although national legislation provides legitimacy for the WUAs, financing measures are insufficient and poorly implemented (Kashaigili et al. 2009). Because WUAs are considered to fall outside of the government administrative system, they have no access to funds from LGAs (WREM International 2015).

IOs' main objective is to ensure crop production through optimal management of water resources and irrigation infrastructure. Moreover, as noted in the *National Irrigation Act 2013* (The United Republic of Tanzania 2013a), IOs shall promote equitable water distribution, water conservation and environmental protection. Other responsibilities comprise: preparation of O&M plans, maintain a register of landholders and irrigators; assist the NIC or LGAs in collection of fees; keep an inventory of irrigation assets; keep records of water flows; and resolve disputes. The *National Irrigation Act 2013* also mandates that once an IO is registered, all irrigators with agricultural lands within a designated irrigation scheme shall become members of the organisation and will be bound by the by-laws of the IO.

The Kiwere and Magozi irrigation schemes each have their own IO, constituting two WUGs within the WUA of the Little Ruaha River, which is the direct water source for both schemes and a tributary to the Great Ruaha River. Each IO has its own set of by-laws aimed at tackling water-related issues within the irrigation schemes. At the time of completion of this thesis, both IOs were reviewing their current by-laws, but only the Magozi IO was able to provide a copy of the document to be studied as part of this thesis (see Appendix G).

At the local level in Tanzania, administrative structures under DCs are wards, which in turn, are constituted by groups of villages. According to the *National Irrigation Policy,* wards act as a linking body between farmers and DCs. One of their main competencies in irrigation is to verify farmers' requests for intervention to be provided by the district. To be considered by the ward councils, such requests must first obtain approval at the village level. Village authorities also have the responsibility to monitor the implementation of irrigation development programs (The United Republic of Tanzania 2010) and, in consultation with IOs, allocate plots on an irrigation scheme (The United Republic of Tanzania 2013a).

Table 6-4 **Key responsibilities of water management authorities in Tanzania**

Institutions	**Key responsibilities**
National Ministry of Water and Irrigation	Assessment, management and planning of the nation's water resources. Policy orientation, development and review Establishment of databases and information management systems Definition of perimeters of Basins, sub-basins and groundwater recharge areas Resolution of national level conflicts among sectors Implementation of the water law Coordinate the planning and preparation of Basin plans
National Irrigation Commission	Advise the government on implementation and review of the National Irrigation Policy and related legislation Plan, design, construct, supervise and administer irrigation projects Coordinate irrigation interventions by development partners and other stakeholders Approve construction of irrigation works, standards and guidelines for the development and management of irrigation and drainage Promote efficient water use and Integrated Water Resources Management approach
Basin Water Boards	Water resources assessment, monitoring and regulation Data collection, processing and analysis Water allocation, pollution control, preparation of water utilisation plans Collection of various fees and charges Resolution of conflicts Conduct research (solely or collaboratively)
Catchment and sub-Catchment Water Committees	Preparation and implementation of catchment plans Resolution of conflicts within the catchments
Zonal Irrigation and Technical Services Units	Provide LGAs, IOs and the private sector with support on capacity building and all aspects of irrigation development
District Councils	Planning and development of water resources Participate in the preparation of Basin plans Assessment of water demands Protection of natural resources in villages and wards Establishment of water management by-laws and resolution of conflicts
Water User Associations	Management of allocated water resources Mediation of disputes among users and between groups Collection of data Participation in the preparation of water utilisation plans Conservation and protection of water sources and catchment areas (pollution) Efficient and effective water use and ensuring return flows Enforcement of the law and implementation of conditions of water rights Representation in Basin Boards and Catchment Committees.

Table 6-4 **Key responsibilities of water management authorities in Tanzania**

Institutions	**Key responsibilities**
Irrigators Organisations	Promotion of equitable water distribution, water conservation and environmental protection Preparation of O&M plans and carrying out of maintenance works Regulation of land and water use Preparation and maintenance of registers of: landholders and irrigators; irrigation assets; and annual financial accounts Monitoring and keeping records of water flows Assistance in fee collection Dispute resolution

Source: The United Republic of Tanzania (2002) and The United Republic of Tanzania (2013a)

To summarise, Tanzania's water and irrigation institutional framework is articulated upon three parallel lines of governance: a) IWRM institutions (BWBs, CWCs, WUAs and IOs); b) government administrations (LGAs); and c) technical structures (NIC, ZITSUs, RIOs, DIOs). Within each of these three institutional sectors, responsibilities are transferred from the national to the regional and local levels in a trickle-down manner. Over the past decades, continuing restructuring and decentralisation reforms in the public sector have created numerous institutions with vaguely defined and overlapping mandates (WREM International 2015). Hence, poor communication, conflict and competitions for revenue often arise among water-governing institutions both horizontally (across lines of governance) and vertically (across hierarchical levels). For example, IOs are expected to autonomously manage water resources within their designated areas, but their authority is often weak and even may be challenged by other concurrent governing bodies (Mwamakamba et al. 2017). Thus, IOs struggle to comply with the obligations transferred onto them through the subsidiarity principle, partially because of their limitations in terms of leadership, technical skills, financial resources and environmental consideration (The United Republic of Tanzania 2010).

6.5.3 Informal irrigation water management

In many developing countries, informal systems are an important mechanism for delivering justice and resolving conflict regarding matters such as land right and access to public services (UNDP 2012). These are often referred to as traditional or "customary. Across Africa, traditional institutional systems, rooted in pre-colonial times, still prevail, but are often at odds with formal justice set ups - a heritage from colonial ruling (Sokile et al. 2003). Such institutional pluralism –

the coexistence of various state, customary and religious laws - has important implications for land and water rights in Africa (Meinzen-Dick & Nkonya 2007). Water right tend to be linked to land rights, yet many rural Africans lack the literacy skills or financial resources to properly register their rights, thus becoming neglected and even criminalised by the statutory legal system (Maganga 2003). Despite a strong emphasis by Governments on formal laws, 90% of land and related resources (e.g. water) in sub-Sharan Africa are still governed under customary arraignments (Van Koppen et al. 2014). Within the context of water management in Tanzania, Juma and Maganga (2005), differentiate between four types of customary laws, as follows:

- Tribal: specific to ethnic groups;
- Formal: recognised in courts of law;
- Traditional customary: enforced by traditional authorities and strongly undermined by the abolition of chieftaincy in 1962; and
- Living customary: combination of traditional customary law, statutory provision and day-to-day practices.

Arguably, failure to recognise and harmonise the dichotomy between formal and informal rules is one of the key challenges for integrated water resources management in Tanzania (Lankford & Mwaruvanda 2005). Maganga (2003) explains that fragmented planning approaches and inconsistent sectoral strategies in the Tanzanian reforms contributed to increased conflicts over water. For example, in a study of the upper Great Ruaha River catchment, van Koppen et al. (2004) observe that the newly-introduced fee system eroded customary water-sharing principles, thus fuelling upstream vs. downstream conflicts. As upstream users viewed water as a commodity, they no longer felt compelled to rationalise their withdrawals on the grounds of downstream users' needs or environmental requirements. Lankford and Mwaruvanda (2005) propose a framework to integrate formal and informal water rights in the Greater Ruaha River Basin, which proposes altering proportions of water to each user according to changing circumstances. A similar framework would be beneficial at the scale of small-scale irrigation schemes, although the compromise between equity and efficiency is a major challenge in systems equipped with rudimentary infrastructure (see Section 6.3.1).

In Kiwere and Magozi, there are no written norms on how water should be distributed within the irrigation systems. Instead, informal arrangements exist, which are defined by the IO and supposed to be followed by all irrigators (see Section 4.4). In Kiwere, the agreed roster allocates water for tail-enders in the morning and for head-enders in the afternoon. Quotidian disputes are common, yet they tend to be resolved swiftly and in an amicable manner. This is consistent with Lecoutere's (2011) and D'Exelle's (2012) observations on irrigators' behaviours in five small-scale schemes in the Mufindi district, in southern Tanzania. The authors note that fixed water-allocation rules are largely absent, while growers informally agree on water-sharing norms or rotation schedules. Generally, Mufindi irrigators have a clear preference for reconciliation over confrontation regarding water distribution conflicts. During filed experiments, it was found that communicating dissatisfaction was irrigators' preferred way of dealing with conflict – rather than punishment rule-breakers. Lecoutere (2011) concludes that, as part of institutional pluralism, mechanisms of informal water justice are advantageous in the sense that they: i) can reconcile disputes before they escalate into violence; and ii) contribute to the gradual development of more sophisticated resource governance institutions. Nonetheless, pragmatic problem solving has the risk of becoming biased by social power imbalances derived from gender and social status (*Ibid.*).

In Magozi (see Section 4.4) the informal arrangement is such that head-enders withdraw water from the canal at the start of the irrigation season (December to February), whilst tail-enders need to await their turn towards the end of the season (March and May). In dry years, when the river levels are too low to supply enough water for the entire scheme, some areas in will remain fallow or become unproductive. A very similar situation is noted by Lankford (2004) in traditional irrigation systems in the Usangu district in southern Tanzania. Like in Magozi, head-end rice irrigators in Usangu transplant in December-January, while tail-enders hire out their labour as the wait for the water to reach them later in March. In years with low levels of rainfall, only a reduced portion of the area at the top-end of the system is irrigated, with the tail-end left uncultivated.

6.5.4 Policy gap at local (micro) level

Currently, the objective of equity of supply is included in various polices at national (macro) and regional (meso) levels, yet it remains largely unaddressed at the local (micro) level of WUAs. The *National Water Policy 2002* (The United Republic of Tanzania 2002 p. 17) mandates that ‘every citizen has an equal right to access and use of the nation's natural water resources for his and the nations benefit’. Following this general statement, subsequent specific articles on equity of water supply are formulated on the basis of urban water supply and sanitation, without mention of equitable water access rights for irrigation purposes. The *Water Sector Development Strategy 2006* and the Rufiji Basin IWRMD Plan call for equity of supply between regions, districts, communities and activity sectors including hydropower, domestic, irrigation and environmental uses. By contrast, the *Water Resources Management Act 2009, National Irrigation Policy 2010* and *National Irrigation Act 2013* make water equity considerations at the level of the WUAs. Importantly, the *Water Resources Management Act 2009* notes that WUAs shall agree on equitable water reductions among their members in times of drought or restrictions in resources availability. The *National Irrigation Act 2013* specifies that IOs shall monitor and keep records of water flows for irrigation, which should be used to evaluate equity in water distribution.

Many of Tanzania’s IOs have only been operating for a relatively short time, and, thus, are still developing their rules and by-laws. For example, the Magozi IO’s current by-laws address topics such as leadership, membership, meetings, finances, rules and fines, but not water distribution. Instead, only a brief mention is made about irrigators’ rights to use irrigation resources, their obligation to follow rules and the applicable fines (see Appendix G). Given that this is a major concern for most irrigators (see Section 4.5.1), the Magozi IO intends to include equity of water supply as a new objective in their upcoming revised by-laws. However, even if equity becomes recognised in the local by-laws, the issue of rule enforcement still remains. As explained in Section 4.5.1, IOs only have limited powers to resolve local conflicts, which can be escalated to the local government authorities including ward office, region’s office and ultimately, the regional court.

Policy investigations (van Rooyen et al. 2017) carried out on the six irrigation schemes included in this thesis note that lack of effective communication and coordination among various irrigation actors (e.g. farmers, water authorities and policy makers) can be a major factor contributing to low crop productivity and profitability. The authors argue that, beyond technological interventions, improving interactions and interventions of multiple stakeholders can create positive changes within the systems. Thus, Agricultural Innovation Platforms (AIPs) provide a valuable opportunity for all actors to work collaboratively in the identification of challenges and their solutions.

6.5.5 Lack of adequate definition of equity of water distribution

Tanzania's national water and irrigation polices address the objective of equitable water supply from a wide range of angles: socioeconomic development; water security; sustainability; efficiency; pricing; performance monitoring; and evaluation. While the goal is arguably well recognised, the legislative texts have important gaps in the definition and characterisation of water equity.

First, the various pieces of legislation employ the terms *(in)equity*, *(in)equitable*, *(un)equal*, *(un)fair* and *unjust* in an interchanging manner without providing definition for each of them. Also, there is no mention to the differences of connotation between 'egalitarianism' and 'proportionality' in water distribution, or vertical and horizontal equity.

Second, current policies refer to equity of water supply using the expressions 'quantities of water abstracted', 'allocation of water', 'water utilisation', 'water use' and 'water flows'. Only the *National Water Policy 2002* and *Water Resources Management Act 2009* briefly notes the need to develop pricing strategies aimed at favouring equitable water allocation. However, no mention is made about the impacts of reliability on water supply and distribution. The exclusive focus on water extraction is arguably one of the main reasons why the current system in Tanzania fails as a water management tool (van Koppen et al. 2004). In fact, across sub-Saharan Africa, water scarcity is not only a matter of physically scarce resources, but also a result of high seasonal and inter-annual variability.

Thus, there is a need to reformulate the concept of water equity to cover, not only quantities, but also other critical aspects including reliability, obligations, benefits/externalities, decision-making and land rights. Consequentiality, irrigation policies aimed at promoting equitable water distribution within smallholder irrigation schemes should be articulated in a comprehensive manner addressing these six key issues.

6.6 Policy discussion

Drawing from previous literature and insights from the fieldwork, the purpose of this section is to reflect on possible measures that could help mitigate water equity issues within smallholder irrigation schemes. Policy options should be regarded as a first step in evaluating possible improvements to the current system. A first-best policy is that solutions should be proposed and agreed to by irrigators themselves, while external advice plays a supporting role. As noted by Lam (1996), rules that are defined by irrigators who have been in the system for years are more likely to be followed than regulations imposed by irrigation officials who have little involvement with the scheme.

A relevant example of participatory processes is presented by van Rooyen et al. (2017), who investigate the ability of AIPs to facilitate institutional arrangements towards greater performance of smallholder irrigation schemes. One of the first steps in the stakeholder consultation process is to have participants identify specific challenges and opportunities regarding their irrigation systems. Similar participatory methods in the study of water management in rural areas are applied by Abdullaev et al. (2009) in central Asia and Gallego-Ayala and Juízo (2011) in Mozambique. The authors employ the SWOT method of analysis, which consists of evaluating Strengths, Weaknesses, Opportunities and Threats associated with the question of study (Pickton & Wright 1998). These four factors can be grouped by a) their origin, i.e. internal to the organisation (strengths and weakness) or external (threats and opportunities) or b) their impact, i.e. positive (strengths and opportunities) or negative (weaknesses and threats).

In this section, possible policy interventions aimed at improving equity of water supply are investigated based on their positive/negative impacts, and not differentiating between internal and external factors. The type of analysis is employed, for example, by Bruns and Meinzen-Dick (2003) in the evaluation of advantages and disadvantages of various water governance structures. A complete SWOT analysis would require drawing a line between the irrigation schemes (internal) and the other actors (external). However, in this study, irrigation schemes are seen as part of a multi-layer, cohesive system (see Figure 6-2) where roles and responsibilities are often shared or disputed among various actors. As the boundaries between users and stakeholders are often unclear (Campbell et al. 2001), it is difficult to establish a neat distinction between internal and external factors.

6.6.1 Quantity

Water distribution within smallholder irrigation schemes is extremely hard to measure to due technical and cost limitations (see Section 4.4). Although the technology exists, traditional irrigators typically lack the resources and skills to collect, analyse and interpret the data. Hence, it is only with external intervention that previous studies − for example, Anwar and Ul Haq (2013); Hussain et al. (2004) and Lal Kalu et al. (1995) − have been able to quantify water distribution within traditional irrigation schemes. Therefore, the use of sophisticated methods to measure and analyse equity of water supply defies the goal of farmer-led water management, as mandated by the subsidiarity principle.

First, it is important to recognise that employing common metrics of water supply and distribution (e.g. volumes and inequality indices) is currently beyond the capabilities of traditional irrigators'. Instead, alternative measures that are easy to record and interpret would be more beneficial. For instance, irrigators could keep records of water availability at agreed intervals (e.g. weekly) by signalling whether plots are *dry*, *wet* or *flooded*, or, whether water height is '*ankle* or *knee deep*'. Water depths could also be read on scales built into the canals. This record-keeping system could also be applied to note timing of water deliveries to track frequency and reliably of supply.

More accurate measures of water supply could be obtained by using tools such as wetting front detectors and soil moisture sensors. Since 2014, a pilot program in the Kiwere scheme (Stirzaker et al. 2017) has trained irrigators in the use of these tools (named FullStop and The Chameleon), which gives information on soil water and nutrient conditions in real time. Participants use these tools to improve their irrigation scheduling to better suit their crops needs and reduce their labour input. Reportedly, the use of the tools has helped reduce water use by up to two-thirds, improving equity of water distribution and reducing conflicts (Ibid.). While the potential benefits are significant, complex and costly bureaucratic procedures to import the tools into Tanzania hinder their widespread implementation.

Other enhanced agronomic practices include farm levelling and adoption of system of rice intensification (SRI) − first developed in Madagascar in the early 2000s and introduced in 2006 in Tanzania, in the Morogoro area (Katambara et al. 2013). Water availability within the schemes could also be improved by specific infrastructure repair and upgrade works. During the author's fieldwork in Magozi, it was noted that the intake capacity was significantly reduced by siltation of the main canal, which could be mitigated by installation of a silt trap. In the Kiwere scheme, building a small reservoir could increase water availability during the day as this could be filled during the night.

6.6.2 Reliability

Reliability of water supply considers whether water deliveries match irrigators' needs and expectations. During the author's fieldwork, irrigators in Magozi explained that the reliability of their supply was strongly dependent on precipitation and river flows. Reportedly, at the start of the irrigation season (December), they are unable to predict the river levels. However, they know that when it runs too low, there is not enough water flowing into the scheme and such water scarcity aggravates distribution disparities (Lal Kalu et al. 1995).

A possible arrangement to mitigate head-tail inequities would be to supply head-enders first in odd-numbered years, and in even-numbered years deliver water first to tail-enders (Dani & Siddiqi 1987). Additionally, a common cultivation calendar would provide greater reliability of supply, as timing of supply to each part of the scheme would be agreed beforehand at the IO level. Such an arrangement was discussed with irrigators and is planned to be included in future business plans - a key strategy to increase synergy among all members of the IOs (Mwamakamba et al. 2017). In Mozambique, for example, business plans are now required following new national regulations approved in 2015. With the assistance of extension services, the business plans in Tanzania would help coordinating cultivation and harvest among irrigators in order to strengthen their access to markets through greater sale quantities and higher crop prices. During the author's fieldwork, the vast majority of interviewees agreed that greater cooperation is critical for the success of their scheme. However, some were concerned that large and powerful irrigators tend to set the collective rules to their own benefit, whereas the small ones have little negotiating power.

Business plans should also provide specifications for infrastructure maintenance schedules and budgets (Mwamakamba et al. 2017). Currently in Magozi, water fees payed by irrigators contribute to the general IO budget covering a wide range of aspects. As a result, the scheme's mid and long-requirements (e.g. maintenance) are often set aside to prioritise more immediate needs, such as debt repayment (Manero 2016).

6.6.3 Obligations

Irrigators in Kiwere and Magozi generally agree on the need to conduct routine maintenance tasks, such as clearing canals and removing weeds. On the other hand, they lack the capacity to undertake major works (e.g. rebuild control structures or collapsed banks), which typically require expertise and financial support from external agencies (Lam 2006). This situation is common among smallholder organisations in sub-Saharan Africa where deferred maintenance is typically viewed as a government responsibility (Letsoalo & Van Averbeke 2006).

Breakage of maintenance or water-sharing rules is a common motive of dispute among Kiwere and Magozi irrigators. The IO may apply fines, yet when conflict persists or penalties are ignored, matters are escalated to regional authorities. As explained in Section 4.5.1, logistic and bureaucratic constraints pose major access obstacles for ill-resourced irrigators. As an alternative, transferring authority to judge water-related disputes from the regional court to the local IOs would make the legal system more accessible for all irrigators. Nevertheless, in practice, IOs would still struggle to enforce the rules (Mwamakamba et al. 2017). For example, in Kiwere, cutting-off water supply to errant irrigators was debated in an IO meeting held at the time of the author's fieldwork. The majority of attendees voted against, as they view it as ineffective and unjust. First, plots at the tail-end of distributary canals would be inappropriately affected, as their supply is dependent on water flowing through neighbouring upstream plots. Second, discrepancies in obligations between land-owners and tenants mean that cutting off the supply would punish the cultivator, but not the owner who is responsible for paying fees and doing maintenance. This issue also applies to sanctions where errant irrigators are expelled from the schemes. Furthermore, if the land from expelled irrigators becomes uncultivated, it would represent an important opportunity cost.

Progressive fines increasing with the offender's crop production or landholding size may provide a greater disincentive for wealthy irrigators' to break the water-sharing rules. The choice between complying or breaking a set of rules may deepened on the financial benefits obtained by each action. Ostrom (1990) explains that when the benefits from rule compliance are smaller than those obtained from breakage minus sanctions, irrigators would have an incentive to break the rules. Contrary to this theory, van Koppen et al. (2004) note that in the Upper Ruaha catchment in Tanzania, payment for water resulted in increased use by upstream irrigators who saw it as an economic good 'they had paid for'. The authors conclude that, in smallholder irrigation systems, it is preferable to disconnect payment of water services from entitlements of water to eradicate the tendency to overuse the resource.

A key measure to promote respect of rules in irrigation systems is having irrigators themselves monitor their peers' (Ostrom 1990). While monitoring by external actors can be expensive (van Koppen et al. 2004) and ineffective (Lam 1996), monitoring by irrigators tends to reduce opportunistic behaviour by keeping incentives to break rules low and likelihood of discovery high (Ostrom 1992). Nevertheless, a risk exists that monitors will be coerced or assaulted (Ibid.).

6.6.4 Benefits/Externalities

Equity of irrigation benefits is often noted as a desirable objective, for example regarding yields from irrigated crops. As elaborated in Chapter 5, crop production may be associated with adequacy of water supply and location within the irrigation scheme, in a way that water-dissatisfied irrigators suffer from lower yields and higher rates of crop failure. However, IOs have no redistribution mechanisms such as taxes or welfare programs to compensate disadvantaged irrigators for the shortfalls of the irrigation scheme.

Water taxation and fee collection in Tanzania is extremely difficult to enforce among smallholder irrigators (van Koppen et al. 2004). An alternative measure to mitigate the negative consequences of water supply inequities could be to provide water-disadvantaged irrigators with better agricultural improvement opportunities. For example, when implementing innovative practices (e.g. soil moisture detectors or SRI) or training programs (e.g. seed selection, pest control, marketing, etc.), a certain percentage of selected participants shall come from water-disadvantaged parts of the schemes. The difficulty lies in determining who is 'water-disadvantaged', as this remains an ambiguous and variable concept.

Soil erosion, increased salinity and water contamination are important negative externalities that can affect irrigators differentially, depending on their location within the scheme. For example, some tail-enders in Kiwere claimed their crops often became infected with pests and diseases, which allegedly were carried by water flushed into the canal by upstream irrigators. Such conflicts could be mitigated if they were regularly monitored and reported to the IOs, for them to mediate between irrigators regarding negative externalities.

6.6.5 Decision-making

Equity in decision-making is recognised in Tanzania's national policies mandating that all irrigators who own land within an irrigation scheme should become members of the IOs. Membership provides irrigators with rights to vote, raise concerns, make suggestions, be informed of the IOs management (e.g. read financial accounts), elect board members and be elected. The nuance is that irrigators who rent land are not obliged to join the IOs, although they have the right to do so.

In Magozi and Kiwere, many renters are not members of the IO because they are unaware of their participation rights, want to avoid the annual fees or feel unwelcome by landowners (Mdemu et al. 2017). Equity of participation in the decision-making process may also be hindered by social power struggles between groups (Nair 2016). For example, during an IO meeting in Kiwere, the author observed that most young irrigators remained quiet and did not participate in the discussions. IO membership of less-advantaged irrigators could be promoted by establishing a quota system whereby representatives from all sections of the scheme, economic levels, ages and genders are allocated a minimum number of positions within the IOs boards.

Another mechanisms to increase participation and empowerment of less-advantaged irrigators is creating sectoral organisations, for example, at the head, middle and tail sections of the scheme. This measure, which is in line with Ostrom's (1990) principle of nested enterprises, was discussed during qualitative interviews as part of the author's fieldwork. Tail-end irrigators explained that a sectoral organisation would strengthen their voices vis-à-vis head-enders and would protect them from one-on-one conflict and marginalisation.

The overlap and incongruence among various governance structures is a major institutional issue in Kiwere and Magozi, as in many smallholder irrigation schemes in sub-Saharan Africa. Based on observations of the six schemes included in this thesis, Mwamakamba et al. (2017) note that irrigators lack clarity of where government infrastructure ownership ends and where their maintenance responsibilities start. As a result, the schemes were caught in a cycle of government and donor investments, infrastructure deterioration and requests for publicly-funded renewals. The authors state (p. 832) 'clarifying ownership and responsibility for maintenance of each piece of hardware is an essential reform for sustaining irrigation schemes'. Clarification of roles and responsibilities should also apply at regional levels, in order to reduce friction between RBOs and District authorities. For example, development of business plans including irrigation scheduling, financial planning and marketing, could be outsourced to extension officers or other professional service providers who would be compensated based on their performance (Lam 1996).

6.6.6 Land rights

Recognition of land rights is fundamental for participation in the irrigation scheme, including membership of IO, access to water and contribution to maintenance. Land renters often find themselves in vulnerable positions where they have no voice within the IOs or they are mistreated by landowners. Some renters have been cultivating in the schemes for a long time, while others only participates on a year-by-year basis, as they search the best opportunities in other scheme. Thus, landowners often see renters as 'outsiders' who seek to benefit themselves in the short term, at the expense of the collective system. On the other hand, renters argue that they are often the object of false accusations and discriminatory behaviour.

Clarification of land rights needs to be carefully elaborated, as customary rules may contradict those of the IO. For instance, in Kiwere, an irrigator claimed to be the 'owner' of his plot, as he was fully dedicated to its cultivation and the only one paying fees, doing maintenance, etc. However, according to the land registry, his elderly father was the rightful owner, although he had not participated in the irrigation scheme for a number of years.

In Kiwere and Magozi, irrigators are often unaware of the exact area they cultivate as they lack the tools to do accurate measurements. In 2015, researchers from Ardhi University carried out a detailed mapping of both schemes (see Section 2.4.3). The information is now available to all irrigators and is valuable for a number of purposes, such as clarifying ownership, irrigation scheduling and fee collection. The main problem resides in the difficulty of keeping the maps up-to-date. As farm plots are sold, inherited, added or abandoned the schemes may face what Meinzen-Dick and Nkonya (2007) call ‘cadastre-disaster’ – a situation where the cost of regularly updating land tenure data largely exceeds the benefits derived from it. As a result, over time, the original information is likely to become obsolete and of limited use. In Tanzania, maintaining accurate maps is one of the responsibilities of the NIC.

Table 6-5 **Possible water equity policy interventions**

Equity aspect	Action	Advantages	Disadvantages	Reference
Quantity	Non-metric water measures and manual record keeping	Low-cost and accessible to all. Greater understanding of water supply across the schemes	Low accuracy and proneness to subjective interpretation	van Koppen et al. (2004)
Quantity	Soil moisture detectors	Reduced water use and labour input. Increased water availability for downstream users	Expensive import costs due to bureaucratic hurdles.	Stirzaker et al. (2017)
Quantity	Improved agronomic practices	Reduced crop water demands, labour and chemical inputs. Higher yields	Barriers to innovate, e.g. access to training, willingness to change and take risks,	Kashaigili et al. (2009)
Quantity /Reliability	Infrastructure upgrades	Reduced water losses and easier maintenance/ Greater supply availability and reliability for downstream farms.	High costs and external intervention required	Lam (1996)
Reliability	Alternate head/tail in priority of supply	Reduced inequities between head and tail-enders	Needs revision during drought years to find a compromise between efficiency and equity	Dani and Siddiqi (1987)
Reliability	Communal cultivation calendar	Collective marketing to achieve higher crop prices. Greater certainty of supply for all irrigators	Difficulty in satisfying individual and collective interests at the same time	Mwamakamba et al. (2017)
Reliability	O&M specific budget	Improved infrastructure operability. Reduced conflict over maintenance works	Lack of financial management skills.	Lam (2006)
Obligations	Transfer of water-judging authority to IOs	Legal system more accessible for all irrigators	Subject to corruption and conflict of interest.	van Koppen et al. (2004)
Obligations	Errant irrigators to be refused water supply or excluded from scheme	Greater disincentive to break the rules.	Downstream irrigators affected by shut-down of supply to upstream neighbours. Discrepancies in obligations between owners and renters	Ostrom (1992)
Obligations	Progressive fines	Greater disincentive for wealthy irrigators to break the rules.	False sense of entitlement to excessive water use.	Ostrom and Benjamin (1993) van Koppen et al. (2004)
Obligations/ Externalities	Monitoring by irrigators	Low-cost. Reduced opportunistic behaviour	Rise to false accusations and corruption; subject to coercion and assault of monitors	Ostrom (1992)

Table 6-5 **Possible water equity policy interventions**

Equity aspect	Action	Advantages	Disadvantages	Reference
Benefits	Targeted training and development opportunities	Increased crop production and incomes	Difficulty in establishing priority order (e.g inter-annual variability)	
Decision-making	IO board quota system	Empowerment of disadvantaged irrigators to form part of the ruling committee	Contradiction of the current voting system based on IO members freedom to vote	
Decision-making	Sectoral organisations	Empowerment of disadvantaged irrigators (e.g. tail-enders). Reduced conflict among single individuals	Additional layer of bureaucracy within the IO	Ostrom and Benjamin (1993); Quinn et al. (2007)
Decision-making	Clarification of institutional responsibilities	Reduced overlap and conflict between IO, District authorities, RBWB and national government	Lack of financial resources for all institutions to fulfil their duties	Kashaigili et al. (2009)
Decision-making	Agency-managed rules	Effective in complex, large systems. Greater transparency and lesser conflict of interest between users and leaders of IO	Disregard customary rules. Failure of irrigators to fulfil their individual obligations	Lam (1996)
Land rights	Clarifying roles and responsibilities between owners and renters	Reduced conflict over maintenance/fees. Empowerment of renters to participate in IOs	Need to avoid clashes between customary and IO rules	
Land rights	Use of cadastre information (maps)	Accuracy and transparency regarding land tenure.	Difficulty in maintaining cadastre up-to-date.	van Koppen et al. (2004) Mdemu et al. (2017)

6.7 Conclusions

This chapter reviews Tanzania’s water and irrigation policies in terms of their equity of water supply objective. A framework for the analysis of equity of irrigation water supply is proposed, comprising six key aspects: quantity; reliability; obligations; benefits/externalities; decision-making; and land rights. Such multi-dimensional approach is important because the core issue of water management in Tanzania lies, not only on physical scarcity, but also on numerous other factors, such as unpredictability of supply and poor governance (van Koppen et al. 2004).

A careful examination of Tanzania’s water and irrigation policies suggests that the equity goal is well recognised at the national (macro) level, yet there is a significant gap at the local (micro) scale. After decades of policy decentralisation and following the subsidiarity principle, local water-governing groups (WUAs) bear the responsibility of managing their own resources. However, poorly defined goals and lack of resources often mean that equity of water supply is well beyond the IOs’ capabilities.

Drawing from the literature and the examples of the Kiwere and Magozi, there are various challenges and opportunities in the pursuit of equity of water supply within smallholder irrigation schemes. This chapter provides a basis for considering options in reference to the six key aspects of the water equity analysis framework and include, among others, redefinition of water measuring standards; development of business plans (including common calendar and maintenance budget); clarification of responsibilities (e.g. owners/renters, RWBs/district authorities); empowerment of water-disadvantaged irrigators (e.g. IO board quota system, targeted education programs); monitoring by irrigators; and technological improvements (e.g. soil monitoring, infrastructure upgrades). While these are general recommendations, policies addressing water issues at local levels should be proposed and agreed to by irrigators themselves so as to ensure solutions are tailored to their specific needs and capabilities.

Chapter 7 Conclusions

7.1 Background and summary of research questions

High economic inequalities pose a major obstacle to poverty reduction, especially in developing areas like SSA. While the association between growth-poverty-inequality is well understood at regional and country levels, it remains largely understudied at the local (micro) scales, such as rural communities.

Over 70 percent of the world's poor live in rural areas where agriculture is their main source of livelihoods and food security. It is within this context that irrigation is recognised as an effective strategy to increase agricultural benefits (e.g. crop production and incomes) and reduce irrigators' exposure to hydro-climatic risks. A topic of much debate in the literature is the linkage between irrigation and inequalities, which is typically addressed at the scale of river basis or large irrigation schemes. But important inequalities also exist within smallholder agricultural communities and a key question is: do inequities in irrigation water supply play a role in aggravating or reducing economic inequalities? This thesis responds to this question and research gap through its four main goals, namely to:

1. Estimate the level of economic inequality within smallholder irrigation schemes in sub-Saharan Africa and its decomposition by types of economic activity.
2. Identify the key linkages perceived by smallholder irrigators between water supply and economic inequalities.
3. Evaluate the relative impact of water supply on irrigated crop income and production within smallholder irrigation schemes.
4. Understand the shortfalls of Tanzania's water and irrigation polices in terms of equity of supply and propose policy options to be considered by local actors.

Each of these research objectives is addressed in a separate chapter, thus contributing to the overarching goal of the thesis in an orderly and consistent manner.

This PhD thesis draws from the support of a broad, government-funded research project in Zimbabwe, Tanzania and Mozambique investigating strategies to increase water productivity and profitability within six smallholder irrigation schemes. The six communities of study vary in size and number of members, but share common characteristics of smallholder irrigation: small plot sizes dependence on the farm as a main source of family income (Nagayets 2005). Across the six communities, 402 households were interviewed as part of a project-led survey in 2014. Because of certain research advantages in the institutional framework and the irrigation schemes, Tanzania was selected to carry out more in-depth investigations in this PhD.

In 2015 the author spent three months doing fieldwork in the Kiwere and Magozi schemes, where 156 irrigators were interviewed. The research methods used in this PhD thesis consist of a combination of qualitative and quantitative, i.e. mixed-methods. Specific techniques include inequality analysis and decomposition, tests of statistical significance, thematic analysis, spatial analysis and multiple regression modelling.

7.2 Main findings

Chapter 3 evaluates the level of income inequality and its decomposition within six smallholder irrigation schemes in Zimbabwe, Tanzania and Mozambique. The first important finding is that income inequalities (Gini Index) at these small scales are considerably high and largely exceed disparities at country level. From a policy perspective, this suggests that national statistics – commonly used to define livelihood strategies – may overlook significant disparities at local levels. For example, The Tanzanian Ministry of Finance and Economic Affairs (The United Republic of Tanzania 2009a) argues that, given the country's relatively low levels of inequality (Gini Index 0.38), income redistribution is not likely to be effective in achieving significant poverty reduction. By contrast, the results of this thesis show that this is not reflective of the situation in Kiwere and Magozi (Gini Index 0.60 and 0.58). The second key finding is that households with diversified livelihood activities have significantly higher income than those relying exclusively on agriculture – as suggested by non-parametric tests of statistical significance (Wilcoxon rank-sum and Kolmogorov-Smirnov). Interestingly, a Theil Index decomposition reveals that over 90 percent of total inequality (except in Mozambique where the population sample is very small) is driven by the *within* group, and not the *between* group component. Finally, a Gini decomposition by income source and marginal effects analyses indicate that agriculture has an equalising effect, whereas business and self-employment;

salaries; and other income sources have mixed effects that generally lack statistical significance. Thus, strategies aimed to improve livelihoods and lessen inequality levels within smallholder irrigation schemes could be two-fold: a) removing entry-barriers into more gainful, non-farm activates; and b) promoting income equalising activities such as agriculture to reduce *within* group inequalities. Importantly, chapter 3 notes that negative incomes − a common issue in the study of agricultural livelihoods – entail strong limitation in Gini decomposition analysis, which are discussed further in Appendix D.

Chapter 4 investigates the linkages between irrigation water supply and economic inequalities within the Kiwere and Magozi schemes, located in southern Tanzania. As in most traditional irrigation systems in Tanzania, and elsewhere in the developing world, there are no objective measures of water deliveries in Kiwere and Magozi, given the lack of flow meters and manual records. To overcome this data gap and in contrast with the majority of previous studies of inequity of water supply, Chapter 4 employs irrigators' perceptions as a proxy for actual water supply. Answers to open-ended questions were synthesised into common themes through thematic analysis, thus pointing out the key linkages between water and economic inequalities.

The most original finding of Chapter 4 is that inequality of water supply affects irrigators through complex human and social mechanisms that, until now, have not been identified by the irrigation literature. These include the amount of time and effort spent waiting and quarrelling about water, which is a major opportunity cost for irrigators who could, otherwise, pursue other more gainful activities (e.g. marketing their crops, labouring, running non-farm business, etc.). Irrigators who are at the centre of water conflicts often become unwelcome by their peers and leaders, and, thus, remain excluded from collaborative initiatives such as marketing, training and finance. Moreover, when irrigators are affected by water scarcity, their livelihoods may become dependent on labour, land rental and small loans provided by better-off irrigators located in water-abundant parts of the scheme. Further in Chapter 4, in-depth interviews reveal that current rule-enforcement and prosecution arrangements may be biased against the poor. Chapter 4 also presents that results of crop yield and yield gap analyses in Magozi, indicating that irrigators who are dissatisfied with their water supply tend to suffer from lower yields, higher land failure rates and greater financial losses than the rest.

Chapter 5 carries out multiple regression analyses to test the hypotheses that adequacy of water supply (and proximity to the system's intake) are positively associated with irrigation incomes and crop yields. Two OLS regression models are built. In the first model, income from irrigated crops is the dependent variable and the model combines data from the Kiwere and Magozi schemes. The second model sets paddy rice yields as the dependent variable and uses pooled data from 2014 and 2015 in Magozi. The theoretical models (with all independent variables) are formulated in logarithmic and linear forms and are tested using backward elimination and General-to-specific methods, in order to check robustness of the results. In the income model, water satisfaction is not significant, thus failing to confirm the formulated hypotheses. Significant factors include crop type, irrigated area, age, education and household size. The association between irrigated crop incomes and human factors suggests that, rather than focusing on technical aspects of irrigation, policies targeting poverty reduction through irrigation development might benefit from considering a broad range of intervention measures. In the paddy yield model, satisfaction of water supply is positive and significant, thus failing to reject the hypothesis. The negative and significant influence of the year dummy raises questions about the exposure of irrigated agriculture to hydro-climatic risks derived from inter-annual rainfall variability. Interestingly, in both income and yield models farm location appears to be significant, but not in the hypothesised linear manner. When distance to intake is converted into a trichotomous variable, dummies for head and tail location are negatively associated with incomes and yields. An important consideration is that, not only water-stress is an issue for tail-enders, but excessive water use is possibly detrimental for head-enders too.

Chapter 6 regards to policy issues related to equity of irrigation water supply. An analytical framework is used that comprises policy implication and six key water equity aspects: quantity; reliability; obligations; externalities; decision-making; and land rights. Tanzania's water and irrigation policies are examined in terms of their equity of water supply objective. One of the main findings is that, after decades of power decentralisation, local water-governing groups (WUAs) now bear the responsibility of equity of water supply, but such obligation remains well beyond their actual capabilities. In fact, Irrigators Organisations lack the resources and governance capacity to define, monitor and enforce equity of irrigation water supply, as well as other IWRM principles like reduction of non-beneficial water uses (i.e. losses) and environmental sustainability. Hence, based on the irrigation water equity framework, Chapter 6 highlights the pros and cons of possible interventions targeting greater equity of water supply within smallholder irrigation schemes. Importantly, volumetric measures of water equity commonly discussed in the literature are far removed from traditional irrigators' practices and capacities. Therefore, an alternative form of accounting for water deliveries is required, possibly with irrigators' personal observations as a low-cost, accessible proxy. Furthermore, national, regional and local water governing institutions often overlap and conflict with each other – an issue that could be mitigated by clearly defining rights, responsibilities and sources of funding.

7.3 Literature contributions

This thesis provides a valuable insight into the association between water supply and economic inequalities within smallholder irrigation schemes in Tanzania. The work contributes to the existing literature gap in several ways.

First, it provides empirical evidence of high income inequities at local scales, thus responding to the 'need for deeper micro empirical work on growth and distributional change' (Ravallion 2001 p. 1807). As national statistics may overlook welfare impacts and be deceptive for development policy (Ibid.), the results of this thesis supports the need for a locally-based approach to define polices regarding the poverty-growth-inequality triangle.

Second, this thesis identifies limitations in the Gini index decomposition in the presence of negative incomes. This finding is particularly important because such limitations are: a) not discussed by the original authors of the decomposition formulation − Lerman and Yitzhaki (1985) – and b) overlooked by successive studies (Adams 2001; Lopez-Feldman et al. 2007; Möllers & Buchenrieder 2011). Theoretical and practical reasons suggest that the misuse of negative incomes in marginal effects and income transfer analyses can lead to erroneous conclusions regarding the inequality increasing/decreasing effect of changes in income distributions.

Third, the open-ended, perception-based research method used in this thesis uncovers new linkages between irrigation water supply and economic inequalities. While previous literature is strongly dominated by quantitative measures of water supply income and crop production, this thesis suggests that human and social factors may be even greater drivers of the economic divide among smallholder irrigation schemes. Erosion of human capital, decline in access to markets, barriers in accessing the legal system, social stratification and exclusion are some of the important linkages that remain ‘invisible’ to common metrics of agricultural production.

Finally, this thesis develops a framework for the comprehensive analysis of equity for irrigation water supply. Although a number of frameworks exist for the analysis of water management and equitable distribution, to the author’s knowledge, this is the first work that systematically compiles all relevant factors for equity of irrigation water supply into a formal analytical framework.

7.4 Limitations

The major limitation in this PhD research is the existence of important data gaps. As detailed in Chapter 2, the initial population sample - obtained in 2014 by the ACAIR project team - for each of the two Tanzanian schemes was 100 households (i.e. 200 in total). However, many observations had missing data and only a reduced number of participants could be re-interviewed in subsequent surveys. Moreover, the use of spatial data was hindered by the difficulties in linking survey answers to cadastral information. In particular, many irrigators were unaware of the right owner of the plots, primarily because of informal land tenure/rental arrangements. Although rigorous methods of analysis were followed in this thesis, the small sample sizes reduced the statistical power of the tests and regression models employed. Data limitations are acknowledged and their consequences discussed in each of the relevant chapters.

A second limitation is given by the access to up-to-date qualitative information. Tanzania is undergoing a continuous transformation of its water and irrigation sector and, thus, much has changed since the author’s completion of fieldwork in August 2015. While time and budget constraints did not permit a second round of fieldwork, the author remained regularly informed through government websites, published literature and direct communication with in-country research teams. Despite efforts to incorporate the most recent information, it is possible that recent changes at local, regional and national levels have occurred that are not reflected in this thesis. At the time of completion of this thesis, the ACIAR-funded project was approved to undergo a second phase from 2017 to 2021. An opportunity exists to fill some of the data gaps and deepen study of water and economic inequalities in Tanzania and, possibly, extend the research to Zimbabwe and Mozambique.

7.5 Opportunities for future research

Based on the findings and gaps of this thesis, there are several opportunities for future research. Increasing equity of irrigation water supply is shown to be an important factor for socio-economic inequalities, which should motivate policymakers to address technical and welfare issues in a conjunctive manner. This is applicable not only to Tanzania, but to most developing countries where irrigation is predominantly based on smallholder systems that typically suffer from persistent heterogeneities in water distribution.

Future research would benefit from investigating in greater detail the drivers of economic inequality at small scales. As Ferreira and Ravallion (2008 p. 25) note ‘understanding of the economic factors behind changes in distribution (or behind the levels and incidence of growth) in developing countries requires a more microeconomic approach’. Within the context of the six irrigation schemes of this thesis, and other smallholder communities elsewhere, it would be worthwhile to investigate the growth elasticity of poverty reduction, following a similar approach of previous studies at national scales (Bourguignon 2003).

Spatial analysis is another area that deserves further consideration in the study of water and economic inequalities. Quantitative results in this thesis suggest that location advantages do not necessarily follow a linear pattern, but could be clustered around different areas of the scheme (i.e. head, middle, tail). Hence, with the adequate amount and quality of data it would be possible to build auto build spatial autoregressive models to explain variations in farm location and production factors, following the examples of Florax et al. (2002) and Zhang et al. (2010). Spatial Lag and Spatial Error models could be the used to better understand possible spatial correlations between water, yields, incomes, human factors, etc. Moreover, as noted by qualitative findings in this thesis, social factors play important roles and, thus, should be considered in regression analyses, for example, including variables for conflict levels or participation in collaborative activities.

From a broader perspective, it would be valuable to assess water supply and economic inequalities in other geographic areas to compare the results to those of Kiwere and Magozi in Tanzania. Although smallholder, traditional schemes across the world share many characteristics, their barriers and opportunities for development can be strongly determined by the local context. The framework for analysis of equity of irrigation water supply developed in this thesis could be applied to other schemes that are part of a Phase II of the ACIAR-funded project. It would also be worthwhile to extend the study to South Asia – an area where important heterogeneities in irrigation water supply exist according to previous studies, but which have not yet been analysed in a comprehensive manner from an equity perspective.

References

Abdullaev, I., Kazbekov, J., Manthritilake, H., & Jumaboev, K. 2009. 'Participatory water management at the main canal: A case from South Ferghana canal in Uzbekistan'. *Agricultural Water Management*, 96(2), 317-329. doi: 10.1016/j.agwat.2008.08.013.

ABS. 2006. 'Household Expenditure Survey and Survey of Income and Housing: User Guide, 2003-04 '. viwed 27 March 2015. http://www.abs.gov.au/ausstats/abs@.nsf/Previousproducts/6503.0Appendix32003-04?opendocument&tabname=Notes&prodno=6503.0&issue=2003-04&num=&view=

ACIAR. 2013. 'Increasing irrigation water productivity in Mozambique, Tanzania and Zimbabwe through on-farm monitoring, adaptive management and Agricultural Innovation Platforms'. http://aciar.gov.au/aifsc/sites/default/files/images/project_summary_with_logos_final_aug13.pdf

Adams, R. H. 2001. 'Nonfarm income, inequality, and poverty in rural Egypt and Jordan'. *World Bank Policy Research Working Paper*, (2572), http://ssrn.com/abstract=632641

Adelman, I., & Morris, C. T. 1973. *Economic growth and social equity in developing countries*: Stanford University Press.

Aghion, P., & Williamson, J. G. 1998. *Growth, inequality, and globalization: theory, history, and policy*: Cambridge University Press.

Aguiar, M. A., & Bils, M. 2011. 'Has Consumption Inequality Mirrored Income Inequality?'. Working Paper No. 16807, http://www.nber.org/papers/w16807.pdf

Ahluwalia, M. S. 1976. 'Inequality, poverty and development'. *Journal of Development Economics*, 3(4), 307-342. doi: 10.1016/0304-3878(76)90027-4.

Ahluwalia, M. S., Carter, N. G., & Chenery, H. B. 1979. 'Growth and poverty in developing countries'. *Journal of Development Economics*, 6(3), 299-341. doi: 10.1016/0304-3878(79)90020-8.

Ahmad, M. D., Turral, H., & Nazeer, A. 2009. 'Diagnosing irrigation performance and water productivity through satellite remote sensing and secondary data in a large irrigation system of Pakistan'. *Agricultural Water Management*, 96(4), 551-564. doi: 10.1016/j.agwat.2008.09.017.

Ahmed, A.-G., Yu, W., & Zhao, X. 2014. 'Rice yield of rural household of Niger state of Nigeria ' *Proceedings of 2013 World Agricultural Outlook Conference* (pp. 205-213).

Alesina, A. 1996. 'Income distribution, political instability, and investment'. *European Economic Review*, 40(6), 1203-1228. doi: 10.1016/0014-2921(95)00030-5.

Alkire, S., & Santos, M. E. 2011. 'Acute multidimensional poverty: A new index for developing countries'. Paper presented at the German Development Economics Conference, Berlin.

Allanson, P. 2005. 'The impact of farm income support on absolute inequality'. Paper presented at the 94th EAAE Seminar, Ashford.

Anand, S., & Kanbur, S. M. R. 1993. 'Inequality and development: A critique'. *Journal of Development Economics*, 41(1), 19. doi: 10.1016/0304-3878(93)90035-L.

Anwar, A. A., & Ul Haq, Z. 2013. 'An old–new measure of canal water inequity'. *Water International*, 38(5), 536-551. doi: 10.1080/02508060.2013.832124.

References

Arndt, T. C., Jones, E. S., & Tarp, F. 2010. *Poverty and Wellbeing in Mozambique: Third National Poverty Assessment*. Ministry of Planning and Development, Mozambique. http://www.preventionweb.net/files/16411_thirdnationalpovertyassessment.pdf

http://eprints.lse.ac.uk/36376/Atkinson, A. B., & Lugo, M. A. (2010). Growth, poverty and distribution in Tanzania (Vol. Working Paper 10/0831). London: International Growth Centre, LSE.

Auffhammer, M., Ramanathan, V., & Vincent, J. R. 2012. 'Climate change, the monsoon, and rice yield in India'. *Climatic Change*, 111(2), 411-424. doi: 10.1007/s10584-011-0208-4.

Australian Government. 2016. 'Private Irrigation Infrastructure Operators Program in New South Wales'. viwed 1 March 2017. http://www.agriculture.gov.au/water/mdb/programmes/nsw/piiop-nsw

Bardhan, P. 2000. 'Irrigation and Cooperation: An Empirical Analysis of 48 Irrigation Communities in South India'. *Economic Development and Cultural Change*, 48(4), 847-865. doi: 10.1086/452480.

Bardhan, P., & Dayton-Johnson, J. 2002. 'Unequal irrigators: Heterogeneity and commons management in large-scale multivariate research'. In E. Ostrom (Ed.), *The drama of the commons* (pp. 87-112). Washington, US: National Academies Press.

Bardhan, P., & Dayton-Johnson, J. 2007. 'Inequality and the governance of water resources in Mexico and South India' *Inequality, cooperation, and environmental sustainability* (pp. 97-130). New York: Russell Sage Foundation.

Barnwal, P., & Kotani, K. 2013. 'Climatic impacts across agricultural crop yield distributions: An application of quantile regression on rice crops in Andhra Pradesh, India'. *Ecological Economics*, 87, 95-109. doi: http://dx.doi.org/10.1016/j.ecolecon.2012.11.024.

Barreiro-Hurle, J. 2012. 'Analysis of incentives and disincentives for rice in the United Republic of Tanzania'. Rome. Technical notes series: http://www.fao.org/3/a-at482e.pdf

Barrett, C. B., Bezuneh, M., & Aboud, A. 2001a. 'Income diversification, poverty traps and policy shocks in Côte d'Ivoire and Kenya'. *Food Policy*, 26(4), 367-384. doi: 10.1016/S0306-9192(01)00017-3.

Barrett, C. B., Reardon, T., & Webb, P. 2001b. 'Nonfarm income diversification and household livelihood strategies in rural Africa: concepts, dynamics, and policy implications'. *Food Policy*, 26(4), 315-331. doi: 10.1016/S0306-9192(01)00014-8.

Battese, G. E., & Coelli, T. J. 1992. 'Frontier Production Functions, Technical Efficiency and Panel Data: With Application to Paddy Farmers in India'. *Journal of Productivity Analysis*, 3(1/2), 153-169. doi: 10.1007/BF00158774.

Baylis, K., Paulson, N. D., & Piras, G. 2011. 'Spatial approaches to panel data in agricultural economics: a climate change application'. *Journal of Agricultural and Applied Economics*, 43(3), 325-338. doi: 10.1017/S1074070800004326.

Bebbington, A. 1999. 'Capitals and Capabilities: A Framework for Analyzing Peasant Viability, Rural Livelihoods and Poverty'. *World Development*, 27(12), 2021-2044. doi: 10.1016/S0305-750X(99)00104-7.

Becker, M., & Johnson, D. E. 1999. 'Rice yield and productivity gaps in irrigated systems of the forest zone of Côte d'Ivoire'. *Field Crops Research*, 60(3), 201-208. doi: 10.1016/S0378-4290(98)00123-3.

Bell, A. R., Ward, P. S., & Shah, M. A. A. 2016. 'Increased water charges improve efficiency and equity in an irrigation system'. *Ecology and Society*, 21(3), 23. doi: 10.5751/ES-08642-210323.

Bellù, L. G., & Liberati, P. 2006. 'Describing Income Inequality: Theil Index and Entropy Class Indexes'. *FAO EASYPol,*, 051, http://www.fao.org/docs/up/easypol/445/theil_index_051en.pdf

Ben-Gal, I. 2005. 'Outlier Detection'. In O. Maimon & L. Rokach (Eds.), *Data Mining and Knowledge Discovery Handbook* (pp. 131-146). Boston, MA: Springer US.

Berg, A. G., & Ostry, J. D. (2011). Equality and efficiency, *Finance & Development*, pp. 12-15. http://econ.tu.ac.th/archan/CHAWIN/TU.124/(1)Inequalities%20and%20Social%20Problems/equality%20efficiency.pdf

Berrebi, Z. M., & Silber, J. 1985. 'The Gini coefficient and negative income: A comment'. *Oxford Economic Papers*, 37(3), 525-526 http://oep.oxfordjournals.org/

Bhaskaran, K., & Smeeth, L. 2014. 'What is the difference between missing completely at random and missing at random?'. *International Journal of Epidemiology*, 43(4), 1336-1339. doi: 10.1093/ije/dyu080.

Bhatta, K. P., Ishida, A., Taniguchi, K., & Sharma, R. 2006. 'Performance of agency-managed and farmer-managed irrigation systems: A comparative case study at Chitwan, Nepal'. *Irrigation and Drainage Systems*, 20(2), 177-191. doi: 10.1007/s10795-005-9001-8.

Bhattarai, M., Sakthivadivel, R., & Hussain, I. 2002. 'Irrigation Impacts on Income Inequality and Poverty Alleviation: Policy issues and options for improved management of irrigation systems.'. http://www.iwmi.cgiar.org/Publications/Working_Papers/working/WOR39.pdf

Bird, J. D. 1991. 'Introducing monitoring and evaluation into main system management ? a low investment approach'. *Irrigation and Drainage Systems*, 5(1), 43-60. doi: 10.1007/BF01102776.

Bjornlund, H., & Pittock, J. 2017. 'Exploring the productivity and profitability of small-scale communal irrigation systems in Sub-Saharan Africa'. *International Journal of Water Resources Development*, 33(5), 685-689. doi: 10.1080/07900627.2017.1326881.

Bjornlund, H., van Rooyen, A., & Stirzaker, R. 2017a. 'Profitability and productivity barriers and opportunities in small-scale irrigation schemes'. *International Journal of Water Resources Development*, 33(5), 690-704. doi: 10.1080/07900627.2016.1263552.

Bjornlund, H., Zuo, A., Wheeler, S., & Parry. 2017b. 'Exploring the influences on gender decision-making and household income amongst small-scale irrigators in Sub-Saharan Africa'. *Manuscript in preparation*

Boehmke, F. J., Schilling, E. U., & Hays, J. C. 2015. 'Missing Data In Spatial Regression'. Paper presented at the Society for PoliticalMethodology Summer Conference, University of Rochester, NY.

Boelens, R., & Dávila, G. 1998. *Searching for equity: conceptions of justice and equity in peasant irrigation*. Assen, The Netherlands: Uitgeverij Van Gorcum.

Bos, M. G. 1997. 'Performance indicators for irrigation and drainage'. *Irrigation and Drainage Systems*, 11(2), 119-137. doi: 10.1023/A:1005826407118.

Bos, M. G., Wolters, W., Drovandi, A., & Morabito, J. A. 1991. 'The Viejo Retamo secondary canal: Performance evaluation case study: Mendoza, Argentina'. *Irrigation and Drainage Systems*, 5(1), 77-88. doi: 10.1007/BF01102778.

Boughton, D., Mather, D., Tschirley, D. L., Walker, T. S., Cunguara, B., & Payongayong, E. M. 2006. 'Changes in Rural Household Income Patterns in Mozambique, 1996-2002, and Implications for Agriculture's Contribution to Poverty Reduction'

References

Bourguignon, F. 1979. ‘Decomposable income inequality measures ’. *Econometrica*, 47(4), 901-920. doi: 10.2307/1914138.
Bourguignon, F. 2003. ‘The growth elasticity of poverty reduction: explaining heterogeneity across countries and time periods’. In T. S. Eicher & S. J. Turnovsky (Eds.), *Inequality and growth: Theory and policy implications*. Cambridge, MA: MIT Press.
Bourguignon, F. 2004. ‘The poverty-growth-inequality triangle’. Paper presented at the Indian Council for Research on International Economic Relations, New Delhi, India.
Bourguignon, F., Ferreira, F. H. G., & Walton, M. 2007. ‘Equity, efficiency and inequality traps: A research agenda’. *The Journal of Economic Inequality*, 5(2), 235-256. doi: 10.1007/s10888-006-9042-8.
Bournaris, T., Berbel, J., Manos, B., & Viaggi, D. 2014. *Economics of Water Management in Agriculture*.
Boyatzis, R. E. 1998. *Transforming qualitative information: Thematic analysis and code development*: sage.
Boyce, C., & Neale, P. 2006. 'Conducting in-depth interviews: A guide for designing and conducting in-depth interviews for evaluation input'. Watertown, MA: http://www2.pathfinder.org/site/DocServer/m_e_tool_series_indepth_interviews.pdf
Bracking, S., & Sachikonye, L. 2010. ‘Migrant Remittances and Household Wellbeing in Urban Zimbabwe’. *International Migration*, 48(5), 203-227. doi: 10.1111/j.1468-2435.2008.00503.x.
Bray, J. R. 2014. ‘Changes in Inequality in Australia and the Redistributional Impacts of Taxes and Government Benefits’ *Measuring and Promoting Wellbeing: How Important is Economic Growth?* (pp. 423-476). Canberra: ANU Press.
Browning, E. K., & Johnson, W. R. 1984. ‘The trade-off between equality and efficiency’. *Journal of Political Economy*, 92(2), 175-203
Bruns, B., & Meinzen-Dick, R. 2003. ‘Framework for water rights: An overview of institutional options’. Paper presented at the International working conference on water rights: institutional options for improving water allocation Hanoi, Vietnam.
Calderón, C., & Servén, L. 2014. 'Infrastructure, growth, and inequality: an overview'. Policy Research Working Paper

https://ssrn.com/abstract=2497234
Campbell, B., Mandondo, A., Nemarundwe, N., Sithole, B., De JonG, W., Luckert, M., et al. 2001. ‘Challenges to proponents of common property recource systems: Despairing voices from the social forests of Zimbabwe’. *World development*, 29(4), 589-600
Canagarajah, S., Newman, C., & Bhattamishra, R. 2001. ‘Non-farm income, gender, and inequality: evidence from rural Ghana and Uganda’. *Food Policy*, 26(4), 405-420. doi: 10.1016/S0306-9192(01)00011-2.
Chambers, R. 1988. *Managing canal irrigation: Practical analysis from South Asia*. Cambridge: Cambridge University Press.
Chen, C.-N., Tsaur, T.-W., & Rhai, T.-S. 1982. ‘The Gini Coefficient and Negative Income’. *Oxford Economic Papers*, 34(3), 473-478 http://www.jstor.org/stable/2662589
Chitale, M. A. 1994. ‘Irrigation for poverty alleviation’. *International Journal of Water Resources Development*, 10(4), 383-391. doi: 10.1080/07900629408722641.
CIA. 2014. ‘The World factbook’. viwed 8 January 2015. https://www.cia.gov/library/publications/the-world-factbook/
Clarke, D. 2014. ‘General-to-specific modeling in Stata’. *Stata Journal*, 14(4), 895-908

Coche, A. G. 1998. 'Supporting aquaculture development in Africa: Research Network on Integration of Aquaculture and Irrigation.'. Accra. CIFA Occasional Paper
Cogneau, D., Bossuroy, T., Vreyer, P. D., Guénard, C., Hiller, V., Leite, P., et al. 2007. *Inequalities and Equity in Africa*. Paris: Agence Française de Développement - Research Department. http://www.afd.fr/webdav/site/afd/shared/PUBLICATIONS/RECHERCHE/Archives/Notes-et-documents/31-notes-documents-VA.pdf
Collins, M., Hornbuckle, J., Veasna, T., Chantha, O., & Kanthel, P. 2014. 'Improved irrigation water management to increase rice productivity in Cambodia '. Paper presented at the Confenrece A Policy dialogue on rice futures: Rice-based farming systems research in the Mekong region, Phnom Penh, Cambodia.
Conceição, P., Levine, S., Lipton, M., & Warren-Rodríguez, A. 2016. 'Toward a food secure future: Ensuring food security for sustainable human development in Sub-Saharan Africa'. *Food Policy*, 60, 1-9. doi: 10.1016/j.foodpol.2016.02.003.
Cowell, F. A. 2008. *Measuring Inequality* LSE Perspectives in Economic Analysis, http://www.academia.edu/163544/Measuring_Inequality
Cremers, L., Ooijevaar, M., & Boelens, R. 2005. 'Institutional reform in the Andean irrigation sector: Enabling policies for strengthening local rights and water management'. *Natural Resources Forum*, 29(1), 37-50. doi: 10.1111/j.1477-8947.2005.00111.x.
Creswell, J. W. 2013. *Qualitative Inquiry and Research Design: Choosing Among Five Approaches*. Thousand Oaks, CA: SAGE Publications.
Creswell, J. W., & Clark, V. L. P. 2007. 'Designing and conducting mixed methods research'
Cribb, J., Hood, A., Joyce, R., & Phillips, D. 2013. *Living standards, poverty and inequality in the UK: 2013*. (1909463094). IFS Reports, Institute for Fiscal Studies. http://www.ifs.org.uk/comms/r81.pdf
Cullis, J., & van Koppen, B. 2007. 'Applying the Gini Coefficient to measure inequality of water use in the Olifants River water management area, South Africa'. IWMI Research Report 113, http://www.iwmi.cgiar.org/Publications/IWMI_Research_Reports/PDF/PUB113/RR113.pdf
D'Exelle, B., Lecoutere, E., & Van Campenhout, B. 2012. 'Equity-Efficiency Trade-Offs in Irrigation Water Sharing: Evidence from a Field Lab in Rural Tanzania'. *World Development*, 40(12), 2537-2551. doi: 10.1016/j.worlddev.2012.05.026.
Dalton, H. 1920. 'The Measurement of the Inequality of Incomes'. *The Economic Journal*, 30(119), 348-361. doi: 10.2307/2223525.
Dani, A. A., & Siddiqi, N. 1987. 'Institutional innovations in irrigation management'. In G. o. N. International Irrigation Management Institute (IIMI) and Water and Energy Commission Secretariat (WECS) of the Ministry of Water Resources (Ed.), *Public Intervention in Farmer-Managed Irrigation Systems* (pp. 71). Digana Village via Kandy, Sri Lanka.
Daniel, W. T., III. 2010. 'Qualitative Interview Design: A Practical Guide for Novice Investigators'. *The Qualitative Report*, 15(3), 754
Dayton-Johnson, J. 1999. 'Irrigation organization in Mexican unidades de riego: Results of a field study'. *Irrigation and Drainage Systems*, 13(1), 57-76. doi: 10.1023/A:1006253923143.

References

Dayton-Johnson, J. 2000a. 'Choosing rules to govern the commons: a model with evidence from Mexico'. *Journal of Economic Behavior & Organization*, 42(1), 19-41. doi: 10.1016/s0167-2681(00)00073-1.

Dayton-Johnson, J. 2000b. 'Determinants of collective action on the local commons: a model with evidence from Mexico'. *Journal of Development Economics*, 62(1), 181-208. doi: http://dx.doi.org/10.1016/S0304-3878(00)00080-8.

De Gregorio, J., & Lee, J.-w. 2002. 'Education and income inequality: new evidence from cross-country data'. *The review of income and wealth*, 48(3), 395-416. doi: 10.1111/1475-4991.00060.

de Sousa, W., Ducrot, R., Munguambe, P., Bjornlund, H., Machava, A., Cheveia, E., et al. 2017. 'Irrigation and crop diversification in the 25 de Setembro irrigation scheme, Mozambique'. *International Journal of Water Resources Development*, 33(5), 705-724. doi: 10.1080/07900627.2016.1262246.

Deaton, A. 1997. *The analysis of household surveys: a microeconometric approach to development policy*. Washington, DC: World Bank Publications.

Deininger, K., & Olinto, P. 1999. 'Asset distribution, inequality, and growth'. World Bank Policy Research: https://ssrn.com/abstract=630745

Deininger, K., & Squire, L. 1998. 'New ways of looking at old issues: inequality and growth'. *Journal of Development Economics*, 57(2), 259-287. doi: 10.1016/S0304-3878(98)00099-6.

Deininger, K. W. 1996. 'A new data set measuring income inequality'. *The World Bank economic review*, 10(3), 565-591. doi: 10.1093/wber/10.3.565.

Deltas, G. 2003. 'The small-sample bias of the Gini coefficient: Results and implications for empirical research'. *Review of Economics and Statistics*, 85(1), 226-234. doi: 10.1162/rest.2003.85.1.226.

Devereux, S. 2016. 'Social protection for enhanced food security in sub-Saharan Africa'. *Food Policy*, 60, 52-62. doi: 10.1016/j.foodpol.2015.03.009.

Diemer, G., & Vincent, L. 1992. 'Irrigation in Africa: The failure of collective memory and collective understanding'. *Development Policy Review*, 10(2), 131-154. doi: 10.1111/j.1467-7679.1992.tb00009.x.

Dietz, T., Ostrom, E., & Stern, P. C. 2003. 'The Struggle to Govern the Commons'. *Science*, 302(5652), 1907-1912. doi: 10.1126/science.1091015.

Dollar, D., & Kraay, A. 2002. 'Growth Is Good for the Poor'. *Journal of Economic Growth*, 7(3), 195-225. doi: 10.1023/A:1020139631000.

Ducrot, R., & Bourblanc, M. 2017. 'Promoting equity in water access: the limits of fairness of a rural water programme in semi-arid Mozambique'. *Natural Resources Forum*, 41(3), 131-144. doi: 10.1111/1477-8947.12128.

Dunn, O. J. 1961. 'Multiple Comparisons Among Means'. *Journal of the American Statistical Association*, 56(293), 52-64. doi: 10.2307/2282330

Edwards, W. 2013. 'Your Farm Income Statement '. viwed 26 March 2015. http://www.extension.iastate.edu/agdm/wholefarm/html/c3-25.html

El-awad, O. M., Gowing, J. W., & Mawdsley, J. A. 1991. 'An approach to multi-criterion evaluation of irrigation system performance: Principles and a case study in Sudan'. *Irrigation and Drainage Systems*, 5(1), 61-75. doi: 10.1007/BF01102777.

Emery, M., & Flora, C. 2006. 'Spiraling-Up: Mapping Community Transformation with Community Capitals Framework'. *Community Development*, 37(1), 19-35. doi: 10.1080/15575330609490152.
Escobal, J. 2001. 'The determinants of nonfarm income diversification in rural Peru'. *World Development*, 29(3), 497-508. doi: 10.1016/S0305-750X (00)00104-2
FAO. 1986. 'Women in irrigated agriculture in Africa'. Proceedings of the Consultation on Irrigation in Africa, Lome, Togo
FAO. 2002. 'Annex VII - Background Documents: Cropland'. Proceedings of the Second expert meeting on harmonizing forest-related definitions for use by various stakeholders, Rome, Italy. http://www.fao.org/docrep/005/Y4171E/Y4171E20.htm
FAO. 2006. 'Fertilizer use by crop in Zimbabwe'. viwed 1 January 2016. http://www.fao.org/docrep/009/a0395e/a0395e00.HTM
FAO. 2007. 'Mozambique Factsheet'. viwed 11 November 2015. http://www.fao.org/fileadmin/templates/tc/tce/pdf/Mozambique_factsheet.pdf
FAO. 2011. 'Crops statistics: Concepts, definitions and classifications'. viwed 12 April 2017. http://www.fao.org/economic/the-statistics-division-ess/methodology/methodology-systems/crops-statistics-concepts-definitions-and-classifications/en/
FAO. 2015a. 'Enhancing Water Use Efficiency in Small Scale Irrigation: The Application of FAO's MASSCOTE Approach '. Sanliurfa, Turkey http://www.fao.org/3/a-i4820e.pdf
FAO. 2015b. 'Smallholders dataportrait'. viwed 10 November 2015. http://www.fao.org/economic/esa/esa-activities/esa-smallholders/dataportrait/farm-size/en/
FAO. 2016. 'AQUASTAT'. viwed 27 Fbruary 2017. http://www.fao.org/nr/water/aquastat/countries_regions/tza/index.stm
FAO and DWFI. 2015. 'Yield gap analysis of field crops - Methods and case studies'. Rome. FAO Water Reports: http://www.fao.org/3/a-i4695e.pdf
Ferreira, F. H., & Ravallion, M. 2008. 'Global poverty and inequality: a review of the evidence'. *World Bank Policy Research Working Paper Series, Vol*
Ferreira, L. 1996. 'Poverty and inequality during structural adjustment in rural Tanzania'. *Policy Reserach Working Paper*, http://www-wds.worldbank.org/servlet/WDSContentServer/WDSP/IB/1996/08/01/000009265_3961019224817/Rendered/PDF/multi0page.pdf
Filmer, D., & Pritchett, L. H. 2001. 'Estimating wealth effects without expenditure Data—Or tears: An application to educational enrollments in states of india'. *Demography*, 38(1), 115-132. doi: 10.2307/3088292
Finn, A., Leibbrandt, M., & Woolard, I. 2009. 'Income and expenditure inequality: Analysis of the NIDS Wave 1 dataset'. *National Income Dynamics Study Discussion Paper*, (5), http://www.nids.uct.ac.za/publications/discussion-papers/wave-1-papers/96-nids-discussion-paper-no05/file
Florax, R. J., Voortman, R. L., & Brouwer, J. 2002. 'Spatial dimensions of precision agriculture: a spatial econometric analysis of millet yield on Sahelian coversands'. *Agricultural Economics*, 27(3), 425-443. doi: 10.1111/j.1574-0862.2002.tb00129.x.
Forouzani, M., & Karami, E. 2011. 'Agricultural water poverty index and sustainability'. *Agronomy for Sustainable Development*, 31(2), 415-431. doi: 10.1051/agro/2010026.

References

Fosu, A. K. 2009. ‘Inequality and the Impact of Growth on Poverty: Comparative Evidence for Sub-Saharan Africa’. *The Journal of Development Studies [H.W.Wilson - SSA]*, 45(5), 726

Fosu, A. K. 2017. ‘Growth, inequality, and poverty reduction in developing countries: Recent global evidence’. *Research in Economics*, 71(2), 306-336. doi: 10.1016/j.rie.2016.05.005.

Francois, L. E., & Maas, E. V. 1999. ‘Crop response and management of salt-affected soils’. In M. Pessarakli (Ed.), *Handbook of plant and crop stress* (pp. 169-201). New York, USA: Marcel Dekker Press Inc.

Gallego-Ayala, J., & Juízo, D. 2011. ‘Strategic implementation of integrated water resources management in Mozambique: An A’WOT analysis’. *Physics and Chemistry of the Earth*, 36(14), 1103-1111. doi: 10.1016/j.pce.2011.07.040.

Giordano, M., & de Fraiture, C. 2014. ‘Small private irrigation: Enhancing benefits and managing trade-offs’. *Agricultural Water Management*, 131, 175-182. doi: 10.1016/j.agwat.2013.07.003.

Global Water Partnership. 2000. 'Integrated Water Resources Management'. Stockholm, Sweden. TAC BAackground papers: http://www.gwp.org/Global/ToolBox/Publications/Background%20papers/04%20Integrated%20Water%20Resources%20Management%20(2000)%20English.pdf

Go, D., Nikitin, D., Wang, X., & Zou, H.-f. 2007. ‘Poverty and inequality in Sub-Saharan Africa: Literature survey and empirical assessment’. *Annals of Economics and Finance*, 8(2), 251-304 http://www.aeconf.com/Articles/Nov2007/aef080203.pdf

Gorantiwar, S. D., & Smout, I. K. 2005. ‘Performance assessment of irrigation water management of heterogeneous irrigation schemes: 1. A framework for evaluation’. *Irrigation and Drainage Systems*, 19(1), 1-36. doi: 10.1007/s10795-005-2970-9.

Grassini, P., van Bussel, L. G. J., Van Wart, J., Wolf, J., Claessens, L., Yang, H., et al. 2015. ‘How good is good enough? Data requirements for reliable crop yield simulations and yield-gap analysis’. *Field Crops Research*, 177, 49-63. doi: https://doi.org/10.1016/j.fcr.2015.03.004.

Groll, T., & Lambert, P. J. 2013. ‘The Pro - Poorness, Growth and Inequality Nexus: Some Findings From a Simulation Study’. *Review of Income and Wealth*, 59(4), 776-784. doi: 10.1111/j.1475-4991.2012.00522.x.

Gutierrez-Montes, I., Emery, M., & Fernandez-Baca, E. 2009. ‘The Sustainable Livelihoods Approach and the Community Capitals Framework: The Importance of System-Level Approaches to Community Change Efforts’. *Community Development*, 40(2), 106-113. doi: 10.1080/15575330903011785.

Hausman, J. A., & Wise, D. A. 1979. ‘Attrition Bias in Experimental and Panel Data: The Gary Income Maintenance Experiment’. *Econometrica*, 47(2), 455-473. doi: 10.2307/1914193.

Hazell, P. B., Poulton, C., Wiggins, S., & Dorward, A. 2007. ‘The future of small farms for poverty reduction and growth’. *International Food Policy Research Institute*, 42, 1. doi:10.2499/97808962976472020vp42

Hirooka, Y., Homma, K., Kodo, T., Shiraiwa, T., Soben, K., Chann, M., et al. 2016. ‘Evaluation of cultivation environment and management based on LAI measurement in farmers' paddy fields in Pursat province, Cambodia’. *Field Crops Research*, 199, 150-155. doi: 10.1016/j.fcr.2016.08.031.

Hsieh, C.-C., & Pugh, M. D. 1993. 'Poverty, income inequality, and violent crime: a meta-analysis of recent aggregate data studies'. *Criminal Justice Review*, 18(2), 182-202. doi: 10.1177/073401689301800203.

Hussain, I. 2005. 'Pro-poor intervention strategies in irrigated agriculture in Asia'. *International Water Management Institute, Colombo, Sri Lanka*

Hussain, I., & Hanjra, M. A. 2003. 'Does irrigation water matter for rural poverty alleviation? Evidence from South and South-East Asia'. *Water policy*, 5(5), 429-442

Hussain, I., & Hanjra, M. A. 2004. 'Irrigation and poverty alleviation: review of the empirical evidence'. *Irrigation and Drainage*, 53, 1-15. doi: 10.1002/ird.114.

Hussain, I., Mudasser, M., Hanjra, M. A., Amrasinghe, U., & Molden, D. 2004. 'Improving Wheat Productivity in Pakistan: Econometric Analysis Using Panel Data from Chaj in the Upper Indus Basin'. *Water International*, 29(2), 189-200. doi: 10.1080/02508060408691768.

Hussain, I., Turral, H., Molden, D., & Ahmad, M.-u.-D. 2007. 'Measuring and enhancing the value of agricultural water in irrigated river basins'. *Irrigation Science*, 25(3), 263-282. doi: 10.1007/s00271-007-0061-4.

Hussein, M. H., Khan, H. W., Alam, Z., & Husain, T. 1987. 'An evaluation of irrigation projects undertaken by AKRSP in the Gilgit District of northern Pakistan'. In G. o. N. International Irrigation Management Institute (IIMI) and Water and Energy Commission Secretariat (WECS) of the Ministry of Water Resources (Ed.), *Public Intervention in Farmer-Managed Irrigation Systems* (pp. 237-261).

IATI. 2014. *Achieving Water Security in Southern Agricultural Corridor of Tanzania. Annual Review*. http://iati.dfid.gov.uk/iati_documents/4407228.odt

IFAD. 2001. 'Assessment of rural poverty in western and central Africa'. viwed 17 March 2015. http://www.ifad.org/poverty/region/pa/english.pdf

Jacoby, J., & Matell, M. S. 1971. 'Three-Point Likert Scales Are Good Enough'. *Journal of Marketing Research*, 8(4), 495-500. doi: 10.2307/3150242

Janssen, M. A., Anderies, J. M., & Cardenas, J.-C. 2011. 'Head-enders as stationary bandits in asymmetric commons: Comparing irrigation experiments in the laboratory and the field'. *Ecological Economics*, 70(9), 1590-1598. doi: 10.1016/j.ecolecon.2011.01.006.

Jayne, T. S., Yamano, T., Weber, M. T., Tschirley, D., Benfica, R., Chapoto, A., et al. 2003. 'Smallholder income and land distribution in Africa: implications for poverty reduction strategies'. *Food Policy*, 28(3), 253-275. doi: https://doi.org/10.1016/S0306-9192(03)00046-0.

Jemmali, H., & Abu-Ghunmi, L. 2016. 'Multidimensional analysis of the water-poverty nexus using a modified Water Poverty Index: a case study from Jordan'. *Water Policy*, 18(4), 826-843. doi: 10.2166/wp.2016.147.

Jing, C., Shizuan, K., & Zhihui, T. 2010. 'On the Applicability of "Provision-Appropriation" Theory to Irrigation Management: An Analysis Based on Institutional Change in the Dongping Irrigation Area'. *The China Nonprofit Review*, 2(1), 83-99. doi: 10.1163/187650910X12605098379094.

Joshi, N. N., Ostrom, E., Shivakoti, G. P., & Lam, W. F. 1998. 'An Institutional Analysis of the Effects of Different Modes of Assistance on the Performance of Farmer-Managed Irrigation Systems in Nepal'. Proceedings of the Crossing Boubdaries", the seventh annual conference of the International Association for the study of Common Property. http://dlc.dlib.indiana.edu/dlc/bitstream/handle/10535/2163/joshi.pdf?sequence=1

References

Juma, I., & Maganga, F. P. 2005. 'Current reforms and their implications for rural water management in Tanzania'. Paper presented at the African Water Laws: Plural Legislative Frameworks for Rural Water Management in Africa, Johannesburg, South Africa.

Kabubo-Mariara, J., Mwabu, D., & Ndeng'e, G. 2012. 'Institutions, Pro-poor Growth and Inequality in Kenya'. Paper presented at the CSAE 2012 Conference on Economic Development in Africa, Oxford.

Kaczan, D., & Ward, J. 2011. 'Water statistics and poverty statistics in Africa: do they correlate at national scales?'. *Water International*, 36(3), 283-294. doi: 10.1080/02508060.2011.583102.

Kadigi, R. M. J., Mdoe, N. S., Lankford, B. A., & Morardet, S. 2005. 'The value of water for irrigated paddy and hydropower generation in the Great Ruaha, Tanzania'. Proceedings of the East Africa Integrated River Basin Management, Sokoine University of Agriculture, Morogoro, Tanzania. https://cgspace.cgiar.org/handle/10568/38305

Kakwani, N., & Pernia, E. M. 2000. 'What is pro-poor growth?'. *Asian development review*, 18(1), 1-16

Kanbur, R. 2005. 'Growth, inequality and poverrty: some hard questions'. *Journal of International Affairs*, 58(2), 223

Kashaigili, J. J., Kadigi, R. M. J., Lankford, B. A., Mahoo, H. F., & Mashauri, D. A. 2005. 'Environmental flows allocation in river basins: Exploring allocation challenges and options in the Great Ruaha River catchment in Tanzania'. *Physics and Chemistry of the Earth*, 30(11), 689-697. doi: 10.1016/j.pce.2005.08.009.

Kashaigili, J. J., Rajabu, K., & Masolwa, P. 2009. 'Freshwater management and climate change adaptation: Experiences from the Great Ruaha River catchment in Tanzania'. *Climate and Development*, 1(3), 220-228. doi: 10.3763/cdev.2009.0025.

Katambara, Z., Kahimba, F. C., Mahoo, H. F., Mbungu, W. B., Mhenga, F., Reuben, P., et al. 2013. 'Adopting the system of rice intensification (SRI) in Tanzania: A review'. *Agricultural Sciences*, 4(08), 369. doi: 10.4236/as.2013.48053.

Kato, Y., Kamoshita, A., & Yamagishi, J. 2006. 'Growth of Three Rice Cultivars (Oryza sativa L.) under Upland Conditions with Different Levels of Water Supply: 2. Grain Yield'. *Plant Production Science*, 9(4), 435-445. doi: 10.1626/pps.9.435.

Kawachi, I., & Kennedy, B. P. 1997. 'Socioeconomic Determinants of Health: Health and Social Cohesion: Why Care about Income Inequality?'. *BMJ: British Medical Journal*, 314(7086), 1037-1040 http://www.jstor.org

Kawakami, K., & Dion, K. L. 1995. 'Social Identity and Affect as Determinants of Collective Action - toward an Integration of Relative Deprivation and Social Identity Theories'. *Theory & Psychology*, 5(4), 551-577. doi: 10.1177/0959354395054005.

Kessy, A. T., & McCourt, W. 2010. 'Is Decentralization Still Recentralization? The Local Government Reform Programme in Tanzania'. *International Journal of Public Administration*, 33(12-13), 689-697. doi: 10.1080/01900692.2010.514454.

Khagram, S. 2005. 'A Comparative Study of Inequality and Corruption'. *American Sociological Review*, 70(1), 136-157. doi: 10.1177/000312240507000107.

Khepar, S. D., Gulati, H. S., Yadav, A. K., & Brar, T. P. S. 2000. 'A model for equitable distribution of canal water'. *Irrigation Science*, 19(4), 191-197. doi: 10.1007/PL00006712.

Kimmage, K. 1991. 'Small-scale irrigation initiatives in Nigeria: the problems of equity and sustainability'. *Applied Geography*, 11(1), 5-20. doi: 10.1016/0143-6228(91)90002-Q.

Kinsey, B. 2010. 'Poverty dynamics in rural Zimbabwe: The 30 years (lost)'war against poverty''. Paper presented at the Conference Ten Years of 'War against Poverty': What Have We Learned since 2000 and What Should We Do 2010-2020?, Manchester.

Koirala, K. H., Mishra, A., & Mohanty, S. 2016. 'Impact of land ownership on productivity and efficiency of rice farmers: The case of the Philippines'. *Land Use Policy*, 50, 371-378. doi: http://dx.doi.org/10.1016/j.landusepol.2015.10.001.

Kolberg, S. 2012. *Equity and equality in irrigation water allocation under basin closure: concepts and measurement*. (PhD), University of Cordoba, Córdoba, Spain. http://helvia.uco.es/xmlui/bitstream/handle/10396/7686/601.pdf?sequence=1

Komnenic, V., Ahlers, R., & Zaag, P. v. d. 2009. 'Assessing the usefulness of the water poverty index by applying it to a special case: Can one be water poor with high levels of access?'. *Physics and Chemistry of the Earth, Parts A/B/C*, 34(4), 219-224. doi: 10.1016/j.pce.2008.03.005.

Kovacevic, M., & Calderon, M. C. 2014. 'UNDP's Multidimensional Poverty Index: 2014 Specifications'. http://hdr.undp.org/sites/default/files/specifications_for_computation_of_the_mpi.pdf

Krueger, D., & Perri, F. 2006. 'Does income inequality lead to consumption inequality?: Evidence and theory'. *The review of economic studies*, 73(1), 163-193. doi: 10.1111/j.1467-937X.2006.00373.x.

Kruskal, W. H. 1952. 'A Nonparametric test for the Several Sample Problem'. *The Annals of Mathematical Statistics*, 23(4), 525-540. doi: 10.1214/aoms/1177729332.

Kurukulasuriya, P., Kala, N., & Mendelsohn, R. 2011. 'ADAPTATION AND CLIMATE CHANGE IMPACTS: A STRUCTURAL RICARDIAN MODEL OF IRRIGATION AND FARM INCOME IN AFRICA'. *Climate Change Economics*, 2(2), 149-174. doi: 10.1142/S2010007811000255.

Kuznets, S. 1955. 'Economic growth and income inequality'. *The American economic review*, 1-28

Lai, T. L., & Ing, C.-K. 2010. 'Stepwise Regression'. In N. J. Salkind (Ed.), *Encyclopedia of Research Design* (pp. 1450-1451). Thousand Oaks, CA: SAGE Publications, Inc. doi: 10.4135/9781412961288.n444

Lal Kalu, I., Nidhi Paudyal, G., & Das Gupta, A. 1995. 'Equity and efficiency issues in irrigation water distribution'. *Agricultural Water Management*, 28(4), 335-348. doi: 10.1016/0378-3774(95)01161-7.

Lam, W. F. 1996. 'Improving the performance of small-scale irrigation systems: The effects of technological investments and governance structure on irrigation performance in Nepal'. *World Development*, 24(8), 1301-1315. doi: 10.1016/0305-750X(96)00043-5.

Lam, W. F. 2006. 'Designing institutions for irrigation management: Comparing irrigation agencies in Nepal and Taiwan'. *Property Management*, 24(2), 162-178. doi: 10.1108/02637470610658032.

Lankford, B. 2004. 'Irrigation improvement projects in Tanzania; scale impacts and policy implications'. *Water Policy*, 6(2), 89

Lankford, B. 2006. 'Localising irrigation efficiency'. *Irrigation and Drainage*, 55(4), 345-362. doi: 10.1002/ird.270.

Lankford, B., & Mwaruvanda, W. 2005. 'A framework to integrate formal and informal water rights in river basin management'. Proceedings of the African water laws: Plural legislative frameworks for rural water management in Africa. Proceedings of a workshop held in Johannesburg, South Africa, 26-28 January 2005,

Lay, J., Mahmoud, T. O., & M'Mukaria, G. M. 2008. 'Few Opportunities, Much Desperation: The Dichotomy of Non-Agricultural Activities and Inequality in Western Kenya'. *World Development*, 36(12), 2713-2732. doi: 10.1016/j.worlddev.2007.12.003.

Leach, M., & Scoones, I. 2015. *Carbon conflicts and forest landscapes in Africa*. New York, NY: Routledge.

Lecoutere, E. 2011. 'Institutions under construction: resolving resource conflicts in Tanzanian irrigation schemes'. *Journal of Eastern African Studies*, 5(2), 252-273. doi: 10.1080/17531055.2011.571388.

Lecoutere, E., D'Exelle, B., & Van Campenhout, B. 2015. 'Sharing Common Resources in Patriarchal and Status-Based Societies: Evidence from Tanzania'. *Feminist Economics*, 21(3), 142-167. doi: 10.1080/13545701.2015.1024274.

Lehmann, D. R., & Hulbert, J. 1972. 'Are Three-Point Scales Always Good Enough?'. *Journal of Marketing Research*, 9(4), 444-446. doi: 10.2307/3149313

Lerman, R. I., & Yitzhaki, S. 1985. 'Income Inequality Effects by Income Source: A New Approach and Applications to the United States'. *The review of economics and statistics*, 67(1), 151-156. doi: 10.2307/1928447

Letsoalo, S., & Van Averbeke, W. 2006. 'Infrastructural maintenance on smallholder canal irrigation schemes in the north of South Africa'. Proceedings of the International Symposium on Water and Land Management for Sustainable Irrigated Agriculture. https://www.researchgate.net/publication/258446554_INFRASTRUCTURAL_MAINTENANCE_ON_SMALLHOLDER_CANAL_IRRIGATION_SCHEMES_IN_THE_NORTH_OF_SOUTH_AFRICA

Lichtman, M. 2012. *Qualitative Research in Education: A User's Guide: A User's Guide*. Thousand Oaks, CA: SAGE Publications.

Lipton, M., Litchfield, J., & Faurès, J.-M. 2003. 'The effects of irrigation on poverty: a framework for analysis'. *Water Policy*, 5(5-6), 413-427

López-Feldman, A. 2006. 'Decomposing inequality and obtaining marginal effects'. *Stata Journal*, 6(1), 106-111 http://www.stata-journal.com/sjpdf.html?articlenum=st0100

Lopez-Feldman, A., Mora, J., & Taylor, J. E. 2007. 'Does natural resource extraction mitigate poverty and inequality? Evidence from rural Mexico and a Lacandona Rainforest Community'. *Environment and Development Economics*, 12(02), 251-269. doi: 10.1017/S1355770X06003494.

Maganga, F. P. 2003. 'Incorporating customary laws in implementation of IWRM: some insights from Rufiji River Basin, Tanzania'. *Physics and Chemistry of the Earth, Parts A/B/C*, 28(20), 995-1000. doi: 10.1016/j.pce.2003.08.011.

Makombe, G., & Sampath, R. 2003. 'A Comparative Analysis of the Influence of Socioeconomic Variables on the Financial Performance of Smallholder Irrigation Systems in Zimbabwe'. *Water International*, 28(4), 416-421. doi: 10.1080/02508060308691718.

Makombe, G., & Sampath, R. K. 1998. 'An Economic Evaluation of Smallholder Irrigation Systems in Zimbabwe'. *International Journal of Water Resources Development*, 14(1), 77-90. doi: 10.1080/07900629849510.

Malhotra, S. P., Raheja, S. K., & Seckler, D. 1984. 'Performance monitoring in the Warabandi system of irrigation management' *Productivity and equity in irrigation systems* (pp. 69-83). New Delhi: Asish Publishing House.

Manero, A. 2016. 'Income inequality within smallholder irrigation schemes in Sub-Saharan Africa'. *International Journal of Water Resources Development*, 1-18. doi: 10.1080/07900627.2016.1152461.

Manero, A. 2017. 'Income inequality within smallholder irrigation schemes in Sub-Saharan Africa'. *International Journal of Water Resources Development*, 33(5), 770-787. doi: 10.1080/07900627.2016.1152461.

Marques, M. R. 2006. 'Experiences with Micro Agricultural Water Management Technologies: Mozambique '. Pretoria: http://www.sarpn.org/documents/d0002066/Mozambique_AWM_Report.pdf

Mashauri, D. A., & Katko, T. S. 1993. 'Water supply development and tariffs in Tanzania: From free water policy towards cost recovery'. *Environmental Management*, 17(1), 31-39. doi: 10.1007/BF02393792.

Mashindano, O., da Corta, L., Kayunze, K., & Maro, F. 2011. 'Agricultural growth and poverty reduction in Tanzania 2000-2010: where has agriculture worked for the poor and what can we learn from this?'. http://www.chronicpoverty.org/uploads/publication_files/WP208%20Mashindano%20et%20al.pdf

Maskey, R. K., Weber, K. E., & Loof, R. 1994. 'Equity aspects of irrigation development: Evidence from two systems in the hills of Nepal'. *International Journal of Water Resources Development*, 10(4), 431-443. doi: 10.1080/07900629408722645.

Mazingi, L., & Kamidza, R. 2011. 'Inequality in Zimbabwe' *Tearing Us Apart: Inequalities in Southern Africa* (pp. 322-383). Johannesburg: Open Society Initiative for Southern Africa.

McCullough, E. B. 2017. 'Labor productivity and employment gaps in Sub-Saharan Africa'. *Food Policy*, 67, 133-152. doi: 10.1016/j.foodpol.2016.09.013.

McKay, A. 2002. 'Defining and Measuring Inequality'. *Inequality Briefing*, http://www.odi.org/sites/odi.org.uk/files/odi-assets/publications-opinion-files/3804.pdf

McKenzie, D. J. 2005. 'Measuring inequality with asset indicators'. *Journal of Population Economics*, 18(2), 229-260. doi: 10.1007/s00148-005-0224-7.

McSweeney, C., New, M., & Lizcano, G. 2010. 'UNDP Climate Change Country Profiles: Mozambique'. http://country-profiles.geog.ox.ac.uk/

Mdemu, M. V., & Mziray, N. 2014. *Profiles and Situation Report for Magozi and Kiwere Irrigation Schemes- Tanzania*.

Mdemu, M. V., Mziray, N., Bjornlund, H., & Kashaigili, J. J. 2017. 'Barriers to and opportunities for improving productivity and profitability of the Kiwere and Magozi irrigation schemes in Tanzania'. *International Journal of Water Resources Development*, 33(5), 725-739. doi: 10.1080/07900627.2016.1188267.

Meinzen-Dick, R. S., & Nkonya, L. K. 2007. 'Understanding legal pluralism in water and land rights: lessons from Africa and Asia'. In B. v. Koppen, M. Giordano & J. Butterworth (Eds.), *Community-Based Water Law and Water Resource Management Reform in Developing Countries* (pp. 12-27). Cambridge, Mass: CABI.

Merrey, D. J. 1997. *Expanding the frontiers of irrigation management research: Results of research and development at the International Irrigation Management Institute, 1984 to 1995* (Vol. XLII). Colombo, Sri Lanka: IWMI.

Mghase, J., Shiwachi, H., Nakasone, K., & Takahashi, H. 2010. 'Agronomic and socio-economic constraints to high yield of upland rice in Tanzania'. *African Journal of Agricultural Research*, 5(2), 150-158. doi: 10.5897/AJAR09.459

Miller, R. B., & Hollist, C. S. 2007. 'Attrition Bias'. In N. Salkind. (Ed.), *Encyclopedia of Measurement and Statistics* (Vol. 1, pp. 57-60). Thousand Oaks: Sage.

Mine, Y., Stewart, F., Fukuda-Parr, S., & Mkandawire, T. 2013. *Preventing violent conflict in Africa: Inequalities, perceptions and institutions*. Basingstoke: Palgrave Macmillan.

Mishi, S., & Mudziwapasi, L. 2014. 'Remittances and sustainability of family livelihoods in Zimbabwe: Case Study of Chegutu Town'. ERSA working Paper: https://econrsa.org/system/files/publications/working_papers/working_paper_440.pdf

Mishra, A., El-Osta, H., & Gillespie, J. M. 2009. 'Effect of agricultural policy on regional income inequality among farm households'. *Journal of Policy Modeling*, 31(3), 325-340. doi: 10.1016/j.jpolmod.2008.12.007.

Molden, D. J., & Gates, T. K. 1990. 'Performance-measures for evaluation of irrigation-water-delivery systems'. *Journal of Irrigation and Drainage Engineering-Asce*, 116(6), 804-823. doi: 10.1061/(asce)0733-9437(1990)116:6(804).

Molle, F., & Mollinga, P. 2003. 'Water poverty indicators: conceptual problems and policy issues'. *Water policy*, 5(5-6), 529-544

Möllers, J., & Buchenrieder, G. 2011. 'Effects of Rural Non-farm Employment on Household Welfare and Income Distribution of Small Farms in Croatia'. *Quarterly Journal of International Agriculture*, 50(3), 217-235 http://ageconsearch.umn.edu/handle/131983

Mollinga, P. P. 2003. *On the waterfront: Water distribution, technology and agrarian change in a South Indian canal irrigation system*. New Delhi: Orient Blackswan.

Moyo, M., Moyo, M., & van Rooyen, A. 2014. *Baseline Data Survey Report. Mkoba and Silalatshani irrigation Schemes in Zimbabwe*. Unpublished report.

Moyo, M., van Rooyen, A., Moyo, M., Chivenge, P., & Bjornlund, H. 2017. 'Irrigation development in Zimbabwe: understanding productivity barriers and opportunities at Mkoba and Silalatshani irrigation schemes'. *International Journal of Water Resources Development*, 33(5), 740-754. doi: 10.1080/07900627.2016.1175339.

MUVI-SIDO. 2009. 'Iringa Tomato Value Chains Analysis for Local (National) Market '. http://www.tzdpg.or.tz/fileadmin/_migrated/content_uploads/TomatoValueChain_10_Septembe2009_1_.pdf

Mwamakamba, S. N., Sibanda, L. M., Pittock, J., Stirzaker, R., Bjornlund, H., van Rooyen, A., et al. 2017. 'Irrigating Africa: policy barriers and opportunities for enhanced productivity of smallholder farmers'. *International Journal of Water Resources Development*, 33(5), 824-838. doi: 10.1080/07900627.2017.1321531.

Mwaseba, D. L., Kaarhus, R., Johnsen, F. H., Mattee, A. Z., & Mvena, Z. S. K. 2007. 'Rice for Food and Income: Assessing the Impact of Rice Research on Food Security in the Kyela and Kilombero Districts of Tanzania'. *Outlook on Agriculture*, 36(4), 231-236. doi: 10.5367/000000007783418534.

Nagayets, O. 2005. 'Small farms: current status and key trends'. Paper presented at the Future of Small Farms Research Workshop, Wye.

Nair, T. 2016. 'Deepening Divides: Decentralized Development and the 'Tyranny' of Participation'. *Journal of International Development*, 28(8), 1323-1336. doi: 10.1002/jid.3233.
Neumann, K., Verburg, P. H., Stehfest, E., & Müller, C. 2010. 'The yield gap of global grain production: A spatial analysis'. *Agricultural Systems*, 103(5), 316-326. doi: 10.1016/j.agsy.2010.02.004.
Nhamo, N., Rodenburg, J., Zenna, N., Makombe, G., & Luzi-Kihupi, A. 2014. 'Narrowing the rice yield gap in East and Southern Africa: Using and adapting existing technologies'. *Agricultural Systems*, 131, 45-55. doi: 10.1016/j.agsy.2014.08.003.
Nkuba, J., Ndunguru, A., Madulu, R., Lwezaura, D., Kajiru, G., Babu, A., et al. 2016. 'Rice value chain analysis in Tanzania: identification of constraints, opportunities and upgrading strategies'. *African Crop Science Journal*, 24(1), 73-87. doi: 0.4314/acsj.v24i1.8S.
OECD. 2014. 'Terms of Reference. OECD Project on the distribution of household incomes'. http://www.oecd.org/statistics/data-collection/Income%20distribution_guidelines.pdf
OECD. 2015. 'Crop yields (indicator)' (Publication no. 10.1787/49a4e677). Retrieved 11 April 2017 https://data.oecd.org/agroutput/crop-yields.htm
Okun, A. M. 1975. *Equality and efficiency, the big tradeoff*: Brookings Institution Press.
Ortiz, I., & Cummins, M. 2011. 'Global Inequality: Beyond the Bottom Billion – A Rapid Review of Income Distribution in 141 Countries'. *UNICEF Social and economic policy working paper*, http://www.unicef.org/socialpolicy/index_58230.html
Ostrom, E. 1990. *Governing the commons: the evolution of institutions for collective action*. Cambridge;: Cambridge University Press.
Ostrom, E. 1992. 'Crafting institutions for self-governing irrigation systems' (pp. xiv-xiv).
Ostrom, E. 1993. 'Design Principles in Long-Enduring Irrigation Institutions'. *Water Resources Research*, 29(7), 1907-1912. doi: 10.1029/92WR02991.
Ostrom, E., & Benjamin, P. 1993. 'Design principles and the performance of farmer-managed irrigation systems in Nepal'. http://publications.iwmi.org/pdf/H013498.pdf
Ostrom, E., Burger, J., Field, C. B., Norgaard, R. B., & Policansky, D. 1999. 'Revisiting the Commons: Local Lessons, Global Challenges'. *Science*, 284(5412), 278-282. doi: 10.1126/science.284.5412.278.
Ostrom, E., & Gardner, R. 1993. 'Coping with Asymmetries in the Commons: Self-Governing Irrigation Systems Can Work'. *The Journal of Economic Perspectives*, 7(4), 93-112
Pasaribu, S. M., & Routray, J. K. 2005. 'Performance of Farmer-managed Irrigation Systems for Rice Production in East Java Province, Indonesia'. *International Journal of Water Resources Development*, 21(3), 473-491. doi: 10.1080/07900620500139192.
Peabody, D. 1962. 'Two components in bipolar scales: Direction and extremeness'. *Psychological Review*, 69(2), 65-73. doi: 10.1037/h0039737.
Peña, H. 2011. 'Social equity and integrated water resources management' (Report No. 9185321842). Stockholm, Sweden. TAC BAackground papers: http://www.gwp.org/Global/ToolBox/Publications/Background%20papers/15%20Social%20Equity%20and%20Integrated%20Water%20Resources%20Management%20(2011).pdf
Pérez-Foguet, A., & Giné Garriga, R. 2011. 'Analyzing Water Poverty in Basins'. *Water Resources Management*, 25(14), 3595-3612. doi: 10.1007/s11269-011-9872-4.

References

Phansalkar, S. J. 2007. ‘Water, Equity and Development’. *International Journal of Rural Management*, 3(1), 1-25. doi: 10.1177/097300520700300101.

Pickton, D. W., & Wright, S. 1998. ‘What's swot in strategic analysis?’. *Strategic Change*, 7(2), 101-109. doi: 10.1002/(SICI)1099-1697(199803/04)7:2<101::AID-JSC332>3.0.CO;2-6.

Pittock, J., Bjornlund, H., Stirzaker, R., & van Rooyen, A. 2017. ‘Communal irrigation systems in South-Eastern Africa: findings on productivity and profitability’. *International Journal of Water Resources Development*, 33(5), 839-847. doi: 10.1080/07900627.2017.1324768.

Pittock, J., Stirzaker, R., Sibanda, L., Sullivan, A., & Grafton, Q. 2013. *Assessing research priorities for blue water use in food production in southern and eastern Africa*. Canberra: The Australian National University, CSIRO and Food, Agriculture and Natural Resources Policy Analysis Network. http://aciar.gov.au/aifsc/sites/default/files/images/waterreport_final_4.pdf

Prasad, K. C., van Koppen, B., & Strzepek, K. 2006. ‘Equity and productivity assessments in the Olifants River basin, South Africa’. Proceedings of the Natural resources forum,

Quinn, C. H., Huby, M., Kiwasila, H., & Lovett, J. C. 2003. ‘Local perceptions of risk to livelihood in semi-arid Tanzania’. *Journal of Environmental Management*, 68(2), 111-119. doi: 10.1016/S0301-4797(03)00013-6.

Quinn, C. H., Huby, M., Kiwasila, H., & Lovett, J. C. 2007. ‘Design principles and common pool resource management: An institutional approach to evaluating community management in semi-arid Tanzania’. *Journal of Environmental Management*, 84(1), 100-113. doi: 10.1016/j.jenvman.2006.05.008.

Raffinetti, E., Siletti, E., & Vernizzi, A. 2014. ‘On the Gini coefficient normalization when attributes with negative values are considered’. *Statistical Methods & Applications*, 24(3), 507-521. doi: 10.1007/s10260-014-0293-4.

Ram, R. 1988. ‘Economic development and income inequality: Further evidence on the U-curve hypothesis’. *World Development*, 16(11), 1371-1376. doi: 10.1016/0305-750X(88)90211-2.

Ravallion, M. 1997. ‘Can high-inequality developing countries escape absolute poverty?’. *Economics letters*, 56(1), 51-57. doi: 10.1016/S0165-1765(97)00117-1.

Ravallion, M. 2001. ‘Growth, inequality and poverty: looking beyond averages’. *World development*, 29(11), 1803-1815

Ravallion, M. 2014. ‘Income inequality in the developing world’. *Science*, 344(6186), 851-855. doi: 10.1126/science.1251875.

Ravallion, M., & Chen, S. 2003. ‘Measuring pro-poor growth’. *Economics Letters*, 78(1), 93-99. doi: 10.1016/S0165-1765(02)00205-7.

Rawal, V., Swaminathan, M., & Dhar, N. S. 2008. ‘On diversification of rural incomes: A view from three villages of Andhra Pradesh’. *Indian Journal of Labour Economics*, 51(2), http://www.agrarianstudies.org/UserFiles/File/Rawal_et_al_On%20Diversification_of_Rural_Incomes....pdf

Reardon, T., Delgado, C., & Matlon, P. 1992. ‘Determinants and effects of income diversification amongst farm households in Burkina Faso’. *The Journal of Development Studies*, 28(2), 264-296. doi: 10.1080/00220389208422232.

Reardon, T. A. 1997. ‘Using evidence of household income diversification to inform study of the rural nonfarm labor market in Africa’. *World Development*, 25(5), 735-747. doi: 10.1016/S0305-750X(96)00137-4.

República de Moçambique. 2010. 'Estratégia de Irrigação'. Maputo

República de Moçambique. 2014. *Increasing Irrigation Water Productivity in Mozambique, Tanzania and Zimbabwe through On-Farm Monitoring, Adaptive Management and Agricultural Innovation Platforms: Mozambique Case Study*. Maputo, Mozambique:

RGA. 2017. 'About the rice industry'. viwed 12 April 2017. http://www.rga.org.au/the-rice-industry.aspx

Rhodes, J., Bjornlund, H., & Wheeler, S. 2014. *Increasing irrigation water productivity in Mozambique, Tanzania and Zimbabwe through on-farm monitoring, adaptive management and agricultural innovation platforms. Project Baseline Report*. Unpublished report.

Rijsberman, F. R. 2008. 'Water for food: corruption in irrigation systems'. In D. Zinnbauer & R. Dobson (Eds.), *Global corruption report 2008: corruption in the water sector* (pp. 67-84). Cambridge: Cambridge University Press.

Robinson, S. 1976. 'A note on the U hypothesis relating income inequality and economic development'. *The American Economic Review*, 66(3), 437-440

Sadras, V., & Bongiovanni, R. 2004. 'Use of Lorenz curves and Gini coefficients to assess yield inequality within paddocks'. *Field Crops Research*, 90(2), 303-310. doi: 10.1016/j.fcr.2004.04.003.

Safa, M. S. 2005. 'Socio-Economic Factors Affecting the Income of Small-scale Agroforestry Farms in Hill Country Areas in Yemen: A Comparison of OLS and WLS Determinants '. *Small-scale Forest Economics, Management and Policy*, 4(1), 117-134

SAGCOT. 2012. 'Appendix IV: Value Chain and Market Analysis'. http://www.sagcot.com/uploads/media/Appendix_IV-_Value_Chain_and_Market_Analysis_03.pdf

Sahn, D. E., & Stifel, D. 2003. 'Exploring alternative measures of welfare in the absence of expenditure data'. *The review of income and wealth*, 49(4), 463-489. doi: 10.1111/j.0034-6586.2003.00100.x.

Saito, K., Dieng, I., Toure, A. A., Somado, E. A., & Wopereis, M. C. S. 2015. 'Rice yield growth analysis for 24 African countries over 1960–2012'. *Global Food Security*, 5, 62-69. doi: http://dx.doi.org/10.1016/j.gfs.2014.10.006.

Saldias, C., Speelman, S., & Van Huylenbroeck, G. 2013. 'Access to Irrigation Water and Distribution of Water Rights in the Abanico Punata, Bolivia'. *Society & Natural Resources*, 26(9), 1008-1021. doi: 10.1080/08941920.2012.729651.

Sampath, R. K. 1988. 'Equity Measures for Irrigation Performance Evaluation'. *Water International*, 13(1), 25-32. doi: 10.1080/02508068808691984.

Sanmartin, C., Ross, N. A., Tremblay, S., Wolfson, M., Dunn, J. R., & Lynch, J. 2003. 'Labour market income inequality and mortality in North American metropolitan areas'. *Journal of Epidemiology and Community Health*, 57(10), 792-797. doi: 10.1136/jech.57.10.792.

Sarker, M. A. R., Alam, K., & Gow, J. 2012. 'Exploring the relationship between climate change and rice yield in Bangladesh: An analysis of time series data'. *Agricultural Systems*, 112, 11-16. doi: 10.1016/j.agsy.2012.06.004.

Sarris, A., Savastano, S., & Christaensen, L. 2006. *Agriculture and Poverty in Commodity-dependent African Countries: A Rural Household Perspective from the United Republic of Tanzania*. Rome, Italy: FAO.

http://kurt.schmidheiny.name/teaching/ols2up.pdfSchmidheiny, K. (2013). The Multiple Linear Regression Model. Basel, Germany: Unversität Basel.

Schutz, R. R. 1951. ‘On the measurement of income inequality’. *The American Economic Review*, 41, 107-122 http://www.jstor.org/stable/1815968
https://opendocs.ids.ac.uk/opendocs/handle/123456789/3390Scoones, I. (1998). Sustainable rural livelihoods: a framework for analysis (Vol. 72). Brighton, UK: Institute of Development Studies.
Seck, P. A., Tollens, E., Wopereis, M. C. S., Diagne, A., & Bamba, I. 2010. ‘Rising trends and variability of rice prices: Threats and opportunities for sub-Saharan Africa’. *Food Policy*, 35(5), 403-411. doi: 10.1016/j.foodpol.2010.05.003.
Seidl, C., Pogorelskiy, K., & Traub, S. 2012. *Tax Progression in OECD Countries: An Integrative Analysis of Tax Schedules and Income Distributions* doi:10.1007/978-3-642-28317-8
Sekiya, N., Tomitaka, M., Oizumi, N., Pyuza, A. G., Shayo, R. J., Assenga, A. N., et al. 2017. ‘Importance of basic cultivation techniques to increase irrigated rice yields in Tanzania’. *Paddy and Water Environment*, 15(4), 847-859. doi: 10.1007/s10333-017-0597-8.
http://www.ophi.org.uk/wp-content/uploads/Sen-1979_Equality-of-What.pdfSen, A. (1979). Equality of What? Stanford University.
Senadza, B. 2011. ‘Does Non-farm Income Improve or Worsen Income Inequality? Evidence from Rural Ghana’. *African Review of Economics and Finance*, 2(2), 104-121 http://www.african-review.com
Senaratna Sellamuttu, S., Aida, T., Kasahara, R., Sawada, Y., & Wijerathna, D. 2014. ‘How Access to Irrigation Influences Poverty and Livelihoods: A Case Study from Sri Lanka’. *The Journal of Development Studies*, 50(5), 748-768. doi: 10.1080/00220388.2013.841887.
Shariff, A., & Azam, M. 2009. ‘Income inequality in Rural India: Decomposing the Gini by income sources’. *Social Science Research Network*, http://ssrn.com/abstract=1433105
Sharma, A., Varma, S., & Joshi, D. 2008. ‘Social equity impacts of increased water for irrigation’. In U. A. Amarasinghe & B. R. Sharma (Eds.), *Strategic Analyses of the National River Linking Project (NRLP) of India Series 2* (pp. 217-237). Colombo: International Water Management Institute.
Sharma, D. N., & Oad, R. 1990. ‘Variable-time model for equitable irrigation water distribution’. *Agricultural Water Management*, 17(4), 367-377. doi: http://dx.doi.org/10.1016/0378-3774(90)90086-E.
Shively, G., & Yao, R. 2015. ‘Poverty, income inequality and irrigation development: longitudinal evidence from Palawan, the Philippines’. *Asian Journal of Agriculture and Development*, 12(1)
Silva, J. A. 2013. ‘Rural Income Inequality in Mozambique: National Dynamics and Local Experiences’. *The Review of Regional Studies*, 43, 23-50 http://journal.srsa.org/ojs/index.php/RRS/article/view/43.1.2
Silva, J. V., Reidsma, P., Laborte, A. G., & van Ittersum, M. K. 2017. ‘Explaining rice yields and yield gaps in Central Luzon, Philippines: An application of stochastic frontier analysis and crop modelling’. *European Journal of Agronomy*, 82, Part B, 223-241. doi: http://dx.doi.org/10.1016/j.eja.2016.06.017.
Singh, K., & Dey, M. M. 2010. ‘Sources of family income and their effects on family income inequality: a study of fish farmers in Tripura, India’. *Food Security*, 2(4), 359-365. doi: 10.1007/s12571-010-0082-3.

Small, L. E., & Rimal, A. 1996. 'Effects of alternative water distribution rules on irrigation system performance: a simulation analysis'. *Irrigation and Drainage Systems*, 10(1), 25-45. doi: 10.1007/BF01102763.
Smeeding, T. M., O'Higgins, M., & Rainwater, L. 1990. *Poverty, Inequality, and Income Distribution in Comparative Perspective: The Luxembourg Income Study (LIS)*. Hertfordshire: Harvester Wheatsheaf.
Sokile, C. S., Kashaigili, J. J., & Kadigi, R. M. 2003. 'Towards an integrated water resource management in Tanzania: the role of appropriate institutional framework in Rufiji Basin'. *Physics and Chemistry of the Earth*, 28(20-27), 1015-1023
Son, H. H. 2004. 'A note on pro-poor growth'. *Economics Letters*, 82(3), 307-314. doi: 10.1016/j.econlet.2003.08.003.
Srinivasan, T. N. 1977. 'Development, Poverty, and Basic Human Needs: Some Issues'. *Food Research Institute Studies*, 16(2), 11-28
Starkloff, R. 2001. 'Farmers' perceptions of the social mobilization of water user organizations in the Sindh, Pakistan'. Lahora, Pakistan. Working Paper: http://www.iwmi.cgiar.org/Publications/Working_Papers/working/WOR33.pdf
Statistics Canada. 2000. *Understanding Measurements of Farm Income*. Agriculture and Agri-Food Canada and Statistics Canada. http://www5.agr.gc.ca/resources/prod/doc/pol/pub/umfi/pdf/umfi_e.pdf
Steiner, R. A., & Walter, M. F. 1992. 'The effect of allocation and scheduling rules on equity and productivity in irrigation systems'. *Agricultural Water Management*, 21(4), 297-312. doi: http://dx.doi.org/10.1016/0378-3774(92)90052-X.
Stich, A. 1996. 'Inequality and negative income'. Paper presented at the Seminar of economic and social statistics, Cologne.
Stirzaker, R., Mbakwe, I., & Mziray, N. R. 2017. 'A soil water and solute learning system for small-scale irrigators in Africa'. *International Journal of Water Resources Development*, 33(5), 788-803. doi: 10.1080/07900627.2017.1320981.
Stock, J. H., & Watson, M. W. 2003. *Introduction to econometrics - 3rd ed.* (Vol. 104). Boston, MA: Addison Wesley
Stretch, T. 2014. *Generating more profit from your farm business*. South Perth, Australia: Western Australian Agriculture Authority
Sullivan, C. 2002. 'Calculating a Water Poverty Index'. *World Development*, 30(7), 1195-1210. doi: 10.1016/S0305-750X(02)00035-9.
Sullivan, C., Meigh, J., & Lawrence, P. 2006. 'Application of the Water Poverty Index at Different Scales: A Cautionary Tale'. *Water International*, 31(3), 412-426. doi: 10.1080/02508060608691942.
Sullivan, C. A., Meigh, J. R., & Giacomello, A. M. 2003. 'The Water Poverty Index: Development and application at the community scale'. *Natural Resources Forum*, 27(3), 189-199. doi: 10.1111/1477-8947.00054.
Swai, A. 2005. 'Farming as a profitable business in Iringa'. viwed 11 November 2015. http://www.runetwork.org/html/en/articles/2509.html
Swyngedouw, E. 2006. 'Power, water and money: exploring the nexus'. Oxford. Human Development Report 2006: http://hdr.undp.org/sites/default/files/swyngedouw.pdf
Syme, G. J., & Nancarrow, B. E. 1997. 'The determinants of perceptions of fairness in the allocation of water to multiple uses'. *Water Resources Research*, 33(9), 2143-2152. doi: 10.1029/97WR01504.

Syme, G. J., Nancarrow, B. E., & McCreddin, J. A. 1999. 'Defining the components of fairness in the allocation of water to environmental and human uses'. *Journal of Environmental Management*, 57(1), 51-70. doi: 10.1006/jema.1999.0282.

Takane, T., & Gono, H. 2017. 'Smallholder Livelihood Diversification and Income Inequality in Rural Malawi'. *Advances in Social Sciences Research Journal*, 4(13)

Tanzania, T. U. R. o. 2006. *ASDP Basket Fund Financial Mechanism Document*. http://www.kilimo.go.tz/uploads/ASDP_Financial_Mechanism.pdf

The United Republic of Tanzania. 2002. *National Water Policy*. Dodoma. http://www.egov.go.tz/egov_uploads/documents/Water_Policy_en.pdf

The United Republic of Tanzania. 2006. *National Water Sector Development Strategy*. Dodoma, Tanzania. https://www.maji.go.tz/sites/default/files/u12/natinalwaterstrategy1.pdf

The United Republic of Tanzania. 2009a. *Brief 4: An Analysis of Household Income and Expenditure in Tanzania*. Dar es Salaam: Ministry of Finance and Economic Affairs. http://www.repoa.or.tz/documents/brief_4_lr.pdf

The United Republic of Tanzania. 2009b. *The Water Resources Management Act*. Dodoma: the Gazette of the United Republic of Tanzania http://www.tanzania.go.tz/egov_uploads/documents/THE%20WATER%20RESOURCES%20MANAGEMENT%20ACT.pdf

The United Republic of Tanzania. 2010. *National Irrigation Policy*. Dar es Salaam, Tanzania. http://www.waterandnature.org/sites/default/files/national_irrigation_policy_final2010.pdf

The United Republic of Tanzania. 2012. *Local Government Reform Programme* http://emjee.biz/resources/MTR-LGRP-II.pdf

The United Republic of Tanzania. 2013a. *The National Irrigation Act*. Dodoma: Gazette of the United Republic of Tanzania. http://www.parliament.go.tz/assets/uploads/files/1b4f6-Bill-No-6-2013.pdf

The United Republic of Tanzania. 2013b. *Tanzania in figures 2012*. Dar es Salaam: National Bureau of Statistics, Ministry of Finance. http://www.nbs.go.tz/takwimu/references/Tanzania_in_figures2012.pdf

The United Republic of Tanzania. 2014a. 'Kilimo Kwanza'. viwed 21 March 2014. http://tanzaniaembassy.be/joomla/index.php/about-tanzania/the-economy/kilimo-kwanza

The United Republic of Tanzania. 2014b. 'Ministry of Water and Irrigation'. viwed 1 May 2017. https://www.maji.go.tz/?q=en

The United Republic of Tanzania. 2016. *2015 Tanzania in figures*. Dar es Salaam. http://www.nbs.go.tz/nbs/takwimu/references/Tanzania_in_Figures_2015.pdf

The United Republic of Tanzania. 2017. 'National Bureau of Statistics'. viwed 30 March 2017. http://www.nbs.go.tz/

The World Bank. 2011. 'Analyzing Inequality'. viwed 16 March 2014. http://go.worldbank.org/5PI4DL3WD1

The World Bank. 2013. 'Irrigation Development Helps Tanzanian Farmers Thrive'. viwed 30 March 2017. http://www.worldbank.org/en/news/feature/2013/08/30/irrigation-development-helps-tanzanian-farmers-thrive

The World Bank. 2015. 'Data'. viwed 13 January 2015. http://data.worldbank.org/indicator/SI.DST.03RD.20/countries

The World Bank. 2017. 'Understanding poverty'. viwed 16 July 2017. http://www.worldbank.org/en/topic/poverty/overview

Therkildsen, O. 2011. 'Policy making and implementation in agriculture: Tanzania's push for irrigated rice' (Report No. 8776054756). Copenhagen, Denmark https://www.diis.dk/files/media/publications/import/diis_wp_2011-26_til_web.pdf

Tidemand, P., & Msami, J. 2010. 'The Impact of Local Government Reforms in Tanzania'. Dar es Salaam: http://www.repoa.or.tz/documents/10-1_SP_lr.pdf

Tisdell, J. G. 2003. 'Equity and Social Justice in Water Doctrines'. *Social Justice Research*, 16(4), 401-416. doi: 10.1023/A:1026365700255.

Tittonell, P., Shepherd, K. D., Vanlauwe, B., & Giller, K. E. 2008. 'Unravelling the effects of soil and crop management on maize productivity in smallholder agricultural systems of western Kenya—An application of classification and regression tree analysis'. *Agriculture, Ecosystems & Environment*, 123(1–3), 137-150. doi: 10.1016/j.agee.2007.05.005.

Tittonell, P., Vanlauwe, B., de Ridder, N., & Giller, K. E. 2007. 'Heterogeneity of crop productivity and resource use efficiency within smallholder Kenyan farms: Soil fertility gradients or management intensity gradients?'. *Agricultural Systems*, 94(2), 376-390. doi: http://dx.doi.org/10.1016/j.agsy.2006.10.012.

Turner, K., Georgiou, S., Clark, R., Brouwer, R., & Burke, J. 2004. *Economic valuation of water resources in agriculture: From the sectoral to a functional perspective of natural resource management* FAO WATER REPORTS Vol. 27. http://www.fao.org/docrep/007/y5582e/y5582e00.htm#Contents

Uddin, M. J., Quayyum, M., & Salahuddin, K. 2009. 'Intercropping of hybrid maize with short duration vegetables at hill valleys of Bandarban'. *Bangladesh Journal of Agricultural Research*, 34(1), 51-57. doi: 10.3329/bjar.v34i1.5753

UDSM. 2017. 'The Rufiji Basin'. viwed 27 June 2017. http://ira.udsm.ac.tz/rufijibasin/basin.php

UK Department for Work & Pensions. 2014. *Households Below Average Income (HBAI) Quality and Methodology Information Report – 2012/13*. https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/325492/households-below-average-income-quality-methodology-2012-2013.pdf

UN. 2010. *64/292. The human right to water and sanitation*. http://www.un.org/es/comun/docs/?symbol=A/RES/64/292&lang=E

UN. 2013a. 'The Equitable Access Score-card: supporting policy processes to achieve the human right to water and sanitation'. https://www.unece.org/fileadmin/DAM/env/water/publications/PWH_equitable_access/1324456_ECE_MP_WP_8_Web_Interactif_ENG.pdf

UN. 2013b. 'We can end poverty'. viwed 31 March 2014. http://www.un.org/millenniumgoals/pdf/Goal_1_fs.pdf

UN. 2014a. 'Rural Poverty in the Developing World'. viwed 27 May 2014. http://www.un.org/en/globalissues/briefingpapers/ruralpov/developingworld.shtml

UN. 2014b. 'UNdata'. viwed 28 May 2014. http://data.un.org/

UN. 2015. 'Sustainable Development Goals'. viwed 16 July 2017. https://sustainabledevelopment.un.org/sdg10

UN. 2016. 'World Water Assessment Programme '. viwed 25 July 2016. http://www.unesco.org/new/en/natural-sciences/environment/water/wwap/facts-and-figures/all-facts-wwdr3/fact-24-irrigated-land/

UNDP. 2011. 'Tanzania: Country Report on the Millennium Development Goals 2010'. Dar es Salaam: UNDP:

http://www.tz.undp.org/content/dam/tanzania/Tanzania%20MDG%20Report%202010.pdf
UNDP. 2012. 'A study of informal justice systems: access to justice and human rights'. http://www.undp.org/content/undp/en/home/librarypage/democratic-governance/access_to_justiceandruleoflaw/informal-justice-systems.html

UNDP. 2013. 'Zimbabwe - HDI values and rank changes in the 2013 Human Development Report'. *The Rise of the South: Human Progress in a Diverse World*, http://hdr.undp.org/sites/default/files/Country-Profiles/ZWE.pdf

Van Den Berg, M., & Ruben, R. 2006. 'Small-Scale irrigation and income distribution in Ethiopia'. *The Journal of Development Studies*, 42(5), 868-880. doi: 10.1080/00220380600742142.

van Etten, J., van Koppen, B., & Pun, S. 2002. 'Do equal land and water rights benefit the poor? Targeted irrigation development: the case of the Andhi Khola irrigation scheme in Nepal'. http://www.iwmi.cgiar.org/Publications/Working_Papers/working/WOR38.pdf

van Ittersum, M. K., Cassman, K. G., Grassini, P., Wolf, J., Tittonell, P., & Hochman, Z. 2013. 'Yield gap analysis with local to global relevance—A review'. *Field Crops Research*, 143, 4-17. doi: 10.1016/j.fcr.2012.09.009.

van Koppen, B., Sokile, C. S., Hatibu, N., Lankford, B. A., Mahoo, H., & Yanda, P. Z. 2004. 'Formal water rights in rural Tanzania: Deepening the dichotomy'. *International Water Management Institute Working paper*, 71

van Koppen, B., Sokile, C. S., Lankford, B. A., Hatibu, N., Mahoo, H., & Yanda, P. Z. 2007. 'Water rights and water fees in rural Tanzania'. In F. Molle & J. Berkoff (Eds.), *Irrigation water pricing: the gap between theory and practice*. Wallingford: CABI.

Van Koppen, B., Van der Zaag, P., Manzungu, E., & Tapela, B. 2014. 'Roman water law in rural Africa: the unfinished business of colonial dispossession'. *Water International*, 39(1), 49-62

van Rooyen, A. F., Ramshaw, P., Moyo, M., Stirzaker, R., & Bjornlund, H. 2017. 'Theory and application of Agricultural Innovation Platforms for improved irrigation scheme management in Southern Africa'. *International Journal of Water Resources Development*, 33(5), 804-823. doi: 10.1080/07900627.2017.1321530.

Vasilescu, B., Serebrenik, A., & van den Brand, M. 2011. 'You can't control the unfamiliar: A study on the relations between aggregation techniques for software metrics'. Paper presented at the 27th IEEE International Conference on Software Maintenance (ICSM).

Vermillion, D. L., Samad, M., Pusposutardjo, S., Arif, S. S., & Rochdyanto, S. 2000. 'An assessment of the small-scale irrigation management turnover program in Indonesia' (Report No. 9290903929). Colombo, Sri Lanka: http://www3.iwmi.cgiar.org/wp-content/themes/ultimate/pdf/Report38.pdf

Vickers, A. J. 2005. 'Parametric versus non-parametric statistics in the analysis of randomized trials with non-normally distributed data'. *BMC medical research methodology*, 5(1), 35. doi: 10.1186/1471-2288-5-35.

Vidyavathi, V., Dasog, G., Babalad, H., Hebsur, N., Gali, S., Patil, S., et al. 2012. 'Influence of nutrient management practices on crop response and economics in different cropping systems in a vertisol'. *Karnataka Journal of Agricultural Sciences*, 24(4)

Virtanen, P., & Ehrenpreis, D. 2007. 'Growth, Poverty and Inequality in Mozambique'. *Country Study*, 10, http://www.ipc-undp.org/pub/IPCCountryStudy10.pdf

Walker, T. S., & Ryan, J. G. 1990. *Village and household economics in India's semi-arid tropics*. Baltimore, MD: Johns Hopkins University Press.
Wan, G. 2004. 'Accounting for income inequality in rural China: a regression-based approach'. *Journal of Comparative Economics*, 32(2), 348-363. doi: 10.1016/j.jce.2004.02.005.
Wang, Z., Huang, Q., & Giordano, M. 2015. 'The effect of private tubewells on income and income inequality in rural Pakistan'. *Journal of Hydrology*, 527, 50-61. doi: 10.1016/j.jhydrol.2015.04.034.
Watkins, K. 2013. 'Inequality barrier to human development'. viwed 31 March 2014. http://kapuscinskilectures.eu/lectures/inequality-as-barrier-to-human-development/
Wegerich, K. 2007. 'A critical review of the concept of equity to support water allocation at various scales in the Amu Darya basin'. *Irrigation and Drainage Systems*, 21(3-4), 185-195. doi: 10.1007/s10795-007-9035-1.
Wheeler, S. A., Zuo, A., Bjornlund, H., Mdemu, M. V., van Rooyen, A., & Munguambe, P. 2017. 'An overview of extension use in irrigated agriculture and case studies in south-eastern Africa'. *International Journal of Water Resources Development*, 33(5), 755-769. doi: 10.1080/07900627.2016.1225570.
Wheeler, S. A., Zuo, A., & Hughes, N. 2014. 'The impact of water ownership and water market trade strategy on Australian irrigators' farm viability'. *Agricultural Systems*, 129, 81-92. doi: 10.1016/j.agsy.2014.05.010.
Wilk, J., & Jonsson, A. C. 2013. 'From Water Poverty to Water Prosperity—A More Participatory Approach to Studying Local Water Resources Management'. *Water Resources Management*, 27(3), 695-713. doi: 10.1007/s11269-012-0209-8.
Williams, N. E., & Carrico, A. 2017. 'Examining adaptations to water stress among farming households in Sri Lanka's dry zone'. *Ambio*, 46(5), 532-542. doi: 10.1007/s13280-017-0904-z.
Williamson, D. F., Parker, R. A., & Kendrick, J. S. 1989. 'The box plot: a simple visual method to interpret data'. *Annals of internal medicine*, 110(11), 916-921. doi: 10.7326/0003-4819-110-11-916.
Woldenhanna, T., & Oskam, A. 2001. 'Income diversification and entry barriers: evidence from the Tigray region of northern Ethiopia'. *Food Policy*, 26(4), 351-365. doi: 10.1016/S0306-9192(01)00009-4.
Wong, P., & Herath, S. 2014. 'Equity in bulk water allocation: the case of the Mahaweli Ganga Development Project in Sri Lanka'. *International Journal of Water Resources Development*, 30(4), 635-648. doi: 10.1080/07900627.2014.882196.
WREM International. 2015. *Rufiji Basin IWRMD Plan: Final Report, Volume I: Rufiji IWRMD Plan*. Report prepared for the United Republic of Tanzania, Ministry of Water, by WREM International Inc,Atlanta, Georgia, USA,:
Zhang, L., Lei, L., & Yan, D. 2010. 'Comparison of two regression models for predicting crop yield'. Proceedings of the Geoscience and Remote Sensing Symposium (IGARSS), Honolulu, HI
ZIMSTAT. 2013. *Poverty and Poverty Datum Line Analysis in Zimbabwe 2011/12*. Harare: Zimbabwe National Statistics Agency. http://www.zimstat.co.zw/dmdocuments/Finance/Poverty2011.pdf

Appendix A. Household surveys questionnaires

2014 Farm household Survey for ACIAR funded project:

Increasing Irrigation Water Productivity in Mozambique, Tanzania and Zimbabwe through on farm monitoring, adaptive management and agricultural innovation platforms

Introductory Statement

This survey is carried out by Ardhi university, Government of Tanzania, in collaboration with the University of South Australia and the Australian National University as part of the project 'Increasing Irrigation Water Productivity in Mozambique, Tanzania and Zimbabwe through on farm monitoring, adaptive management and agricultural innovation platforms' funded by the Australian International Centre for Agricultural Research. The purpose of the survey is to establish farm and household characteristics of irrigator households as well as how you perceive a number of issues related to your irrigation scheme and your community. We will at least conduct one survey at the beginning of this project and one at the end so that we can identify any changes taking place during the process of implementing the Agricultural Innovation Platform. Your responses to these questions will remain anonymous but you will be given a household ID which is only known to the researchers on the project. This ID will allow us to contact you later and to compare your answers from the first and subsequent surveys. Information will be treated as strictly confidential.

All the questions in this survey are about your farm and household situation during the 2013/14 season. We would like to interview a member of the HH who is either a key decision maker or is actively involved in farming activities within the HH.

Thanks you for your co-operation in this survey and we are looking forward to talk to you again over the coming years.

Name of Irrigation Scheme__________________________________Scheme code: _______________Household Head Name: __________________________

Common Household Name: __________________________Respondent/Interviewee: ____________________________

Relation to HH Head__________________________Interviewer/Enumerator______________________Date:_____________________

1 Questions about your Household

1 Who are the members of your household?(*First ask about the head of household, then list the members of the household as each person relates to the head of household. Then fill out the rest of the table using the below keys.)*

HH No	Name of HH member	Relation to HH Head	*Marital Status*	*Gender*	*Age*	*Education*	*Children Edu. exp.*	*Children not at school*	*Working on farm (%)*	*Working off farm (%)*	*Working away 1=Yes 2=No*	*How long working away*	*Health*
1													
2													
3													
4													
5													
6													
7													
8													
9													
10													
11													

Answer Key:
Marital status: 1=never married; 2=Married/de facto; 3=married but not living with partner; 4=divorced; 5=Separated; 6=Widowed;
Relation to HH Head:1=Head; 2= Husband; 3=wife; 4= Son; 5= Daughter; 6= Parent; 7= Grandchild; 8=Other(Specify)**Gender:**1=male; 2=female **Age:** Please record actual or estimated age in years
Education: 1=no formal schooling; 2=some primary school; 3=completed primary school; 4=some secondary school; 5=completed secondary school; 6=some university or college; 7=Professional College/trade certificate; 8=still at school; 9=not started school yet; 10=other, specify
Children Edu. Exp. (Educational expectations): For each child not yet started school or still attending school, ask: after which year/level do you expect them to finish school?
Children not at school: For children not at school and not having finished high school: Why did they stop going to school? 1=Had to contribute to work on the farm; 2=Had to work off-farm to contribute to the family income; 3=We could not afford to pay the cost of keeping him/her in school; 4=We do not think he/she needs any further schooling; 5=Not yet started schooling 6= Child did not want anymore, 7=Other, specify
Working on farm: % of time spend working on the farm (includes selling or transport produce at the market or processing produce)
Working off-farm: % of time spend working off-farm
Working away: seasonal work away from home: which household members work away from home
How long working away: On average how long time do they spend away from home (1= days, 2= weeks or 3=months). ? Please explore: how many month, week, days etc. to reach percentage
Health: How do you consider each household's members' health: 1=Good (<5 days); 2=infrequently sick (6-10 days); 3=Frequently/regularly sick (>10 days); 4=Bed ridden

2 Was the head of household born in this village **1=Yes:** ☐ **2=No:** ☐

b. If the answer is no to the above question: How many years have you lived in this village?

c. And, why did you move to this village?

d. What is the main language spoken in your hou
(specify)

3 How many years has the household been farming?*Years: Dry land farming* _________ *Irrigation farming*______ *Irrigation scheme*_______

Let's discuss the food security situation of your household

4 Have you faced food shortage (i.e. not sufficient food from your own production) over the last 5 years (2009-2014)?1=Yes☐2=No☐*(If No, go to Q 9)*

7 Out of the last five years, how many years were you faced with food shortages? Number of years? ☐

5On average, during which months do you face food shortage in a given year?(*Please circle the months mentioned*):**J F M A M JJ A S O N D**

6 If you did not have access to an irrigated plot during which months would you face food shortage?(*Please circle the months mentioned):*

J F M A M JJ A S O N D

8What is the main cause of food shortage in your household?

1=Drought ☐ 2= Poor harvest☐ 3= Lost job ☐ 4= Death in the family ☐ 5=Unreliable income ☐

6=Inflation ☐ 7=Theft ☐ 8=family size ☐ 9=Irrigation scheme not functional ☐

10=Other ☐ (specify)

9Have you received food aid in any form over the last five years? 1=Yes ☐2= No☐If yes, how many times? Number of years: ☐

10 Have you sold produce from the irrigation scheme to overcome your food shortage? 1=Yes 2= No

If yes, 1= During a normal year? ☐ 2=During a drought year? ☐

11 If you did not have access to the irrigation scheme, how would you have secured your food needs?

Describe: ☐

12Nutrition and food access; please indicate how often you access the following food items: *(see Answer key below table)*

How often does your household	milk	sugar	Meat	fish	beans	other vegetables	fruits
a. eat/drink							
b. purchase							
Codes frequency: 1= daily, 2 = weekly, 3 = monthly, 4 = seasonally/occasionally, 5 = yearly, 6 = never 7=other (specify)							

13Which of the following assets doesthe household or somebody in your household own?*(Tick all applicable boxes)*

Household assets

1=Generator ☐ 2=Car ☐ 3=Motorbike/scooter ☐ 4=Bicycle ☐
5=Fridge ☐ 6=Sewing machine ☐ 7=Radio ☐ 8=TV ☐
9=Solar panel ☐
10=Borehole/water pump ☐ 11=Mobile phone ☐ 12= others specify ☐

Type of dwelling: 1=Brick ☐ 2=mud, grass

Type of roofing 1=☐ Timber ☐2 Thatched roof ☐; 3=metal or other solid roof ☐

Farm assets:

1=☐Tractor 2=☐Tractor-driven tools3=☐Hand tools4=☐Animal-driven tools5=☐Wheel Barrow 6=☐Ox/donkey cart 7= ☐Other (Specify)
8=☐ Disc plough, 9=☐Harrow Plough

14 Which of the following financial arrangements do you have?*(Tickall applicable boxes)*

1=Functional bank account ☐ 2=Savings account ☐
3=Traditional savings schemes at local community level ☐ 4=Traditional burial schemes at local community level ☐
5=Loan from a financial institution ☐ 6=Loan from an individual (S*pecify e.g. uncle, neighbor, trader etc)* ☐
7=Loan from other institution (*please specify e.g. church, government)* ☐ 8=*Don't know* ☐
9= No account 10=Other (*please specify)* ☐

15 Do you think your participation in the irrigation scheme will provide you with a better life in the future?*(Tick one box only)*

1=Much worse ☐ 3=Better ☐ 5=About the same ☐
2=Worse ☐ 4=Much better ☐ 6=Don't Know ☐
7=No, I think we need to opt out of agriculture to achieve a better life in the future ☐

2 Questions about your Farm

16 a. Next we would like to draw a map that outlines your fields and homestead. Start by showing your homestead compound. Then draw the fields closest and furthest in a picture on the ground. Our enumerator will transcribe this onto this page. Show any major landmarks near your homestead/fields like roads, school, and borehole. (**Draw map and crops grown in the 2013/14 season here).**

16 b. Please tell us about the land you and your household cultivates, who controls it and how (own/lease/share-farm) :(*use keys below to fill out the form) (this should be similar to the areas and crops you have indicated on the map drawn in 16a)*

	Area	*Unit of measurement 1=ha; 2=acres; 3=m^2*	*Who owns*	*Type of ownership*	*Soil type*	*Soil fertility*	*Slope*	*Erosion*
Land which can be irrigated:								
Irrigated plot (IP) 1								
Irrigated Plot 2								
Uncultivated during 13/14								
Farmed without irrigation in 13/14								
Rainfed Land:								
Rainfed Plot (RF) 1								
Rainfed Plot 2								
Uncultivated during 13/14								
Home garden (HG)								
Total land area			NA	NA	NA	NA	NA	NA
Interviewer: add up and make sure that the area for irrigated+rainfed+uncultivated ads up to the total area. If not ask questions until the numbers add up.								

Answer Keys:
Who owns: note the person(s) who controls the land using the number(s) from question 1 i.e.**1=Head; 2= Husband; 3=wife; 4= Son; 5= Daughter; 6= Parent; 7= Grandchild; 8=husband and wife 9=Other(Specify),**
Type of ownership/access: 1= private title and use; 2=Government tenure; 3=Community tenure (no written lease); 4=Leased in (used others land and paid); 5=leased out (others use my land and pay); 6=borrowed land without paying; 7=share cropping in; 8=share cropping out; 9other specify, 10= used land <10 years, 11=used land>10 years, 12 = others use my land without paying
Soil type: 1 = Sandy, 2 = clay, 3 = black soil, 4 = red soil;
Soil fertility: 1 = Very fertile, 2=moderately fertile; 3= infertile;
Slope: 1= flat; 2=slight slope (up to 20%), 3=steep
Erosion: 1=no erosion; 2= moderate erosion; 3=severe erosion

17If rain fed land or irrigated land is uncultivated: Why are you not cultivating all your rain fed/irrigated land?
Please provide the answers here:
(Specifyrainfed/irrigated land)

18Crop production – (please fill out the following table, and check area sizes with question 16, note that the cultivated land should sum up.)

Plot (refer to the map)									
crop name									
type/variety									
area size									
Unit of area (*1=ha; 2=acres*									
tillage implement									
tillage passes [no]									
Date sown									
seed [unit] [unit]									
Farm Yard Manure [unit]									
Other manure. _______									
fertiliser 1, top dress [kg}									
fertiliser 2, basal									
fertiliser 3 ________[kg]									
fertiliser 4 ________[kg]									
total fertl expenses									
herbicide expenses									
fungi/pesticideexp									
% of irrigation water									
Type of harvest									
water expenses									
Cost of non-family									
Date harvested									
Output. [kg]									

Answer Key:
Plot number: for each of plots of crop grown ask which of the plots in question 16 the crops was grown on (eg IP1 or RF 2)
Crop: 1=Maize; 2=Sorghum; 3=Ground nut; 4=Tobacco; 5=Cotton; 6=Cow pea; 7=Pigeon pea; 8=Irish potato; 9=Sweet potato; 10=Tomato; 11=Finger Millet; 12=Bambara nut; 13=Sugar beans; 14=Sun flower; 15=Soya bean; 16=rice; 17=Other cereal crops; 18=Other legume crops; 19=Other vegetables; 20=Fruits; 21=Feed crop, 22= cabbage, 23 = onion, 24=lettuce, 25=carrots, 26=green beans, 27= peppers, 28 chillies
Tillage implement: 1=harrow; 2=disk; 3=rotavator, 4=plough, 5=other, please specify:
Type of harvest: 1=manual; 2=mechanical **Months**-1=Jan; 2= Feb; 3= Mar; 4=Apr; 5=May; 6=Jun; 7=Jul; 8= Aug; 9=Sep; 10= Oct; 11= Nov; 12= Dec

19 What is your use of your main crop products (SHELLED or NOT):

crop name (use code)	% eaten	% seed	% feed	% sold/barter	If sold, specify market channel (code)	Main months of sale	Average price per kg (and range)

Answer Key:
crops 1=Maize, 2=Sorghum, 3=Ground nut, 4=Tobacco, 5= Cotton, 6=Cow pea, 7=Pigeon pea, 8=Irish potato, 9=Sweet potato, 10=Tomato, 11=Finger Millet,12=Bambara nut, 13=Sugar beans, 14=Sun flower, 15=Soya bean, 16=rice, 17=Other cereal crops, 18=Other legume crops, 19=Other vegetables, 20=Fruits, 21=Feed crops, 22= cabbage, 23 = onion, 24=lettuce, 25=carrots, 26=green beans, 27= peppers, 28 chillies
Market channel: 1=farm gate, 2=village market, 3=local collection point, 4= cooperative for bulk sales, 5= regular trader, 6=contract with buyer, 7= regional city, 8= wholesaler
Prices: provide average price, and range if prices differed substantially by time of sales
Months: 1=Jan; 2= Feb; 3= Mar; 4=Apr; 5=May; 6=Jun; 7=Jul; 8= Aug; 9=Sep; 10= Oct; 11= Nov; 12= Dec

20 Which crops have you not yet grown, but would like to adopt?

Crop (use code)	*For what purpose?*	*What prevents you from adoption?*

Answer key Crops 1=Maize; 2=Sorghum; 3=Ground nut; 4=Tobacco; 5= Cotton; 6=Cow pea; 7=Pigeon pea; 8=Irish potato; 9=Sweet potato; 10=Tomato; 11=Finger Millet; 12=Bambara nut; 13 = Sugar beans;14 = Sun flower; 15=Soya bean; 16=rice; 17=Other cereal crops; 18=Other legume crops; 19=Other vegetables; 20=Fruits; 21=Feed crops; other, specify: 22= cabbage, 23 = onion, 24=lettuce, 25=carrots, 26=green beans, 27= peppers, 28 chillies

21Do you think you got the best possible price for your commodities or do you think there are other buyers/market channels that would pay a better price?

1. Yes, there are other buyers that would pay a better price ☐ 2. No, this is the best price I can get ☐ 3. Don’t know ☐

22*If yes in the question above*: Why do you not sell to that buyer/market channel?

Please provide the answer here:

23Did you buy any fertilizer and/or farm chemicals during the 2013/14 season?*(Tick all that apply)*

1=Yes 2=No, If your answer to the above is Yes, tell us more on how these were bought

1. Seller came to the village ☐ 2. I bought it from a wholesale business in a nearby town☐ 3. Through irrigation association☐

4. I bought it on the nearest local market ☐ . 5. Other, specify

24Do you think you could get it cheaper somewhere else?*(Tick one box only)*

1. Yes, there are other sellers that would be cheaper ☐ 2. No, it was the best possible price ☐ 3=*Don't know* ☐

24.1 Do you get subsidized/free inputs (seed, fertilizer)? 1. From government? ☐ 2. From NGOs ☐ 3. No, I don't get those. ☐

25If yes to the above question, why did you not buy it there?

Please provide the answer here:

26Do you commonly need farm equipment that you do not own? 1=Yes ☐2=No ☐. **If yes, how do you commonly get access to equipment?***(Tick all that apply)*

1. Rent itfrom yourirrigation association/cooperative ☐
2. Rent it from a private contractor ☐
3. Rent it from a neighboring farmerfor cash or in-kind ☐
4. Borrow it from a neighboring farmer without payment ☐
5. Other ☐
6. Have no ability to access ☐
7. *Don't know (do not read out only record if no answer)* ☐

27Would better ability to access farm equipment significantly improve the viability/profitability of your land?

1=Yes ☐ 2=No ☐ 3=Don't know ☐

28What are the main constraints to improving the viability/profitability of your land? (rank 1-3)

1= Inputs (seeds fertilizers) ☐ 2=Implements and tools ☐ 3=Knowledge and information ☐
4=Access to functional markets ☐ 5=Access to land/Tenure ☐ 6= Access to water ☐
7=Quality of water ☐ 8= Salinity
9 =Other - specify

3Questions about your Livestock

29Please tell us the details of your livestock production in the 2013/14:*(please use the answer key below to fill out the form)*

	Number currently owned	*Who own/ Control*	How many are used as Draft animals	*Main dry season feed (rank, see codes)*			*Main rainy season feed (rank, see codes)*			*Main dry season water source (rank, see codes)*			*Main rainy season water source(rank, see codes)*			*Costs inputs (MT)*
				1	*2*	*3*	*1*	*2*	*3*	*1*	*2*	*3*	*1*	*2*	*3*	
Cattle																
Donkeys																
Pigs																
Sheep																
Goats																
Chicken																
Ducks																
Other																

Answer key:Number: please provide the number of each category
Who own/control: Who in the Household controland make most decisions regarding these animals: provide number from table in Q1 If more than one provide all person numbers***(1=Head; 2= Husband; 3=wife; 4= Son; 5= Daughter; 6= Parent; 7= Grandchild; 8=husband and wife , 9=Other(Specify),***
Feed, in order of importance rank the three most important feed types: 1=rangelands, 2=crop residues grazed in rain fed fields, 3=crop residues collected in rain fed fields, 4=forage planted in rain fed fields, 5=crop residues grazed in irrigation fields, 6=crop residues collected in irrigation fields, 7=forages planted in irrigation fields, 8=purchased stock feed, 9=other (specify)
Water Source, in order of importance rant the three most important water sources: 1=surface water, 2=wells, 3=river, 4=irrigation scheme, 5=borehole, 6=others (specify)

30 Please tell us the details of your livestock marketing during the 2013/14 season:*(please use the keys below to fill out the form)*

	How many were lost/died (specify)	***How many consumed***	***How many sold***	***If sold, specify market channel (code)***	***When did you sell*** 1=Jan; 2= Feb; 3= Mar; 4=Apr; 5=May; 6=Jun; 7=Jul; 8= Aug; 9=Sep; 10= Oct; 11= Nov; 12= Dec	***Average price per animal (range)***
Donkeys						
Cattle						
Pigs						
Sheep						
Goats						
Chicken						
Ducks						
Other						

Answer Key: Who sold to: 1=Farm gate; 2=village market; 3=local business centre, 4=collection point, 5=sale pen; 6=regional auction, 7=regional town, 8=others (specify)
Prices: provide average price, and range if prices differed substantially across animals and time of sales

31Do you think there are other buyers that would pay a better price?

1. Yes, there are other buyers that would pay a better price ☐ 2. No, it was the best possible price ☐ 3=Don't know ☐

32If yes to the question above, why did you not sell to that buyer/market channel?

Please provide the answer here:

**33Who makes the major decisions in the household over the following crops and livestock?*(If joint decision by several note all relevant*(i.e.1=Head; 2= Husband; 3=wife; 4= Son; 5= Daughter; 6= Parent; 7= Grandchild; 8= Husband and wife; 9=Other (Specify)

	Rain fed crops	*Irrigated crops*	*Cattle*	*Small stock*
What crops/feed to grow				
Use of farm implements				
Buying of inputs				
When to carry out the work				
When and where to sell the products				
How to use the income from sale				

34When making decisions about your farm (what to grow, where to sell, when to irrigate etc.), where do you seek advice from? *(tick all relevant)*

	Rain fed crops		*Irrigated crops*		*Livestock*	
	Source of information	*Relevance*	*Source of information*	*Relevance*	*Source of information*	*Relevance*
What crops/feed to grow						
How to manage the crops/livestock						
Where to sell the outputs						

Answer key:
Sources of information 1=Buyers of my crop/livestock; 2=Sellers of farm input; 3=Extension officer; 4=Farmer group/cooperative; 5=Irrigation association; 6=Research; 7=NGOs; 8=Other farmers; 9=Others (specify)
Relevance: 1=Yes, relevant I follow the advice; 2=Sometimes I follow the advice; 3=No, not relevant, I don't follow the advice.

35If the answer above was 2 or3(sometimes or not relevant), why is it not relevant?

Please provide the answer here:

36 Have you over the last three years, or do you intend to over the next three years: *(Tick all that apply)*

		Last 3 years 1= Yes; 2=No	Next 3 years 1=Yes; 2=No
a.	Increased your irrigated area on an annual basis (that is taking multiple cropping into account)	☐	☐
b.	Acquired additional irrigated land (either purchased, leased or share farmed)	☐	☐
c.	Acquired additional dry farm land (either purchased, leased or share farmed)	☐	☐
d.	Acquired any implements to improve the productivity of your land	☐	☐
e.	Diversified your crops to better deal with risk	☐	☐
f.	Intensified crop production to increase your profit	☐	☐
g.	Specialized on certain crops you are growing to increase your income	☐	☐
h.	Increased the proportion of your production that you are selling rather than consuming	☐	☐
i.	Decreased your irrigated area on an annual basis (that is taking multiple cropping into account)	☐	☐
j.	Disposedof any of your irrigated land (either sold, leased out or share farmed out)	☐	☐
k.	Disposedof any of your dry farm land (either sold, leased out or share farmed out)	☐	☐
l.	Disposed of any implements used to increase the productivity of your land	☐	☐
m.	Changes to the crops you are growing to reduce your workload from farming and accepting a lower farm income	☐	☐
n.	Increased the proportion of your production that you and your family are consuming	☐	☐
o.	Reduced the size of your holding of livestock	☐	☐
p.	Increased the size of your holding of livestock	☐	☐

37Have you used any of these practices on your farm, if so when did you start doing it and are you still doing it? *(Fill all relevant columns)*

Practice	1= Yes; 2=No	*When Adopted (years ago)*	*Do you do this every year?* 1= Yes; 2=No	*Why not Used*
Pumping directly from river independently of scheme				
Establish ground water pump				
Carry water in buckets or other devices from local water source				
Growing cover crop				
Run-off harvesting				
Mulching				
Crop rotation				
Accessing other natural resources such as wood, charcoal, fish etc.				
Planting leguminous crops (e.g. cowpea) to utilize remaining soil moisture after harvest of main crop				
Grow crops or varieties which require less water or have a shorter growing season				

38Do you think that the temperature in your area has generally changed over the past ten years?*(tick one box only)1= Yes* ☐*2= No* ☐
If yes, did it: **1=**increase ☐2=decrease ☐3=became more unpredictable ☐4=pattern changed ☐

39 Do you think that rainfall in your area has generally changed over the past ten years?*1= Yes* ☐*2= No* ☐*(tick one box only)*
If yes, did it:1=increase ☐2= decrease ☐3=became more unpredictable ☐4=pattern changed ☐

4Questions about your Irrigation

40How would you define your right to receive water? E.g.: is it to a certain number of irrigation events, a certain flow rate during a certain period of time?

Please provide the answer here:

41What do you need to do to receive water?*(Tick all that apply)*
1= I have to order it a certain number of days in advance ☐ 2=Irrigation management committee tellsme when I will get the water ☐
3=Set Irrigation Roster (A certain day per week etc) ☐4=Other (*please specify in box):*

42Do you always get all the water you need when you order it?*(Tick one box only)*

1=Never ☐ 2=Rarely ☐ 3=Mostly ☐ 4=Always ☐

43How much do you pay for water? Price per ha/acres or other:

44Do you think that is a reasonable rate for water?*(Tick one box only if the farmer does pay for the water)*
1=Far too expensive ☐ 2=Expensive ☐ 3=Fair ☐ 4=Cheap ☐ 5=Very cheap ☐6= Not applicable

45Apart from paying this amount, do you also have to do some work maintaining the irrigation system?*(Tick one box only)*
1=Yes ☐ 2=No ☐

46 Ifyes to the question above, what and how much?

47 From which type of canal do you receive your water? *(Write the plot number)*
1=Primary ☐ 2=Secondary ☐ 3=Tertiary ☐ 4=Overflow from neighbouring plot ☐ 5=Don’t know

48Is it lined or earthen?*(Tick one box only)*

1=Lined ☐ 2=Earthen ☐ 3=Don't know ☐ 4= Pipe ☐

49 Is it a permanent canal or temporary furrow/canal?*(Tick one box only)*

1=Permanent ☐ 2=Temporary ☐ 3=Don't know ☐

50Where on that canal are your plots located: *(Write where the specific plots are)*

1=Beginning ☐ 2=Middle ☐ 3=End ☐ 4=Don't know ☐

51Overall how satisfied are you with your supply of irrigation water?*(Tick one box only)*

1=Very dissatisfied ☐ 2=Dissatisfied ☐ 3=Neutral ☐ 4=Satisfied ☐ 5=Very satisfied ☐ 6=Don't know ☐

52Do you think water is equitably distributed among the irrigators in your irrigation system?*(Tick one box only)*

1=Totally disagree ☐ 2=Disagree ☐ 3=Neutral ☐ 4=Agree ☐ 5=Strongly agree ☐ 6=Don't know ☐

53How do you determine when to irrigate and how much water to apply?*Please write the answer here:*

54Do you think you could improve the way crops are irrigated? *(Tick one box only)*

1=Yes ☐ 2=No ☐ 3=Don't know ☐

55If yes to the previous question, please explain how?*(Please provide the answer here):*

57 Over the next five years, how do you expect the adequacy, quality and timing of your water supply to change?*(Tick one box only)*

1=Become much worse ☐ 2=Become worse ☐ 3=Stay the same ☐ 4=Improve ☐ 5=Improve greatly ☐ 6=*Don't know* ☐

5Questions about your community

58How satisfied are you with the support you receive from your local community?*(Tick one box only)*

1=Very dissatisfied ☐ 2=Dissatisfied ☐ 3=Neutral ☐ 4=Satisfied ☐ 5=Very satisfied ☐ 6=*Don't know* ☐

58.1 Are you member of any group or association? (Tick)

1=AIP ☐ 2=Farm producer association ☐ 3=Irrigation scheme association ☐ 4= Church group ☐ 5=Others, specify ☐

59 Thinking about your local community, its wellbeing and the support you receive from it, in five yearshow good do you think it will be? *(Tick one box only)*

1=Much worse ☐ 2=Worse ☐ 3=About the same ☐ 4=Better ☐ 5=Much better ☐ 6=*Don't know* ☐

60 Within your irrigation district, do you think there is a significant gap between the poorest and wealthiest families? 1=Yes ☐ 2=No ☐

61 If yes, over the past ten years, has this gap: 1=diminished ☐ 2=about the same ☐ 3=Increased ☐ 4= don't know

62 In the future, do you expect this gap to: 1=diminish ☐ 2=remain the same ☐ 3=Increase ☐ 4= don't know ☐

6Questions about your Values and Attitudes

63In the following sections we would like to explore the values you hold in general terms. Please use a seven-point scale to measure the importance of each value “as a guiding principle in my life”: extremely important (7), strongly important (6), important (5); neutral (4); unimportant (3); strongly unimportant (2); opposed to my values (1).

.

Value List	Rating (1 to 7)	Value that Is Most Important*(tick one only)*	Value that is Least Important*(tick one only)*
Honoring of parents and elders (Show respect)			
Capable (competent, effective, efficient)			
Unity with nature (fitting into nature)			
Choosing own goals (selecting own purposes)			
Wealth(material possessions, money)			
Broad-minded (tolerant of different ideas and beliefs)			
Daring (seeking adventure, risk)			
Healthy (not being sick physically or mentally)			
A spiritual life (emphasis on spiritual not material matters)			
Ambitious (hard working, aspiring)			
Successful (achieving goals)			
Responsible (dependable, reliable)			
Social recognition (respect, approval by others)			
Social justice (correcting injustice, care for the weak)			
Self-respect (belief in one’s own worth)			
Social order (stability of society)			
Loyal (faithful to my friends, group)			
Freedom (freedom of action and thought)			
Independent (self-reliant, self-sufficient)			
Meaning in life (a purpose in life)			

64Please rate your level of agreement with the following statements:(*Please tick the answer agreed with)*

	1=Extremely disagree	*2=Strongly disagree*	*3= Disagree*	*4=Neutra l*	*5=Agree*	*6=Strongly agree*	*7=Extremely agree*
Habits and initiatives							
When I work on the farm, I Do it the way it has always been done							
When I work on the farm, it is something I do without thinking.							
To change the way I am managing my farm would require a big effort							
I am ready to take risks in order to develop new strategies on my farm, e.g. produce new crops and sell them at a new market							
Balance between economic, social and environmental issues							
Decisions about investments at my farm are more about immediate livelihood benefits/solving problems, rather than about long term environmental benefits							
I am more concerned about ensuring immediate livelihood benefits/solving problems than attending to traditional/cultural/social activities or lifestyle							
Investing in long term environmental benefits is more important than attending to traditional/cultural/social activities or lifestyle							
Common property and community engagement							
Land is the most important heritage of the family, more than livestock or other assets.							
Myneighbors' farming practices affect me andmy farming practices							
The cooperation with other community members helps me in case of emergency							
I am interested, active and motivated to undertake activities in the community							
Engagement with external actors							
I invested more in my farm because of the knowledge that I gained from other farmers							
I have started new collaborations with organizations/partners outside the community that help me to engage in new value chains							
Leadership, communication, information sharing							
I have a clear understanding of my role and responsibility within the community.							
I trust the leaders in my community.							
We have structures that help us to communicate and share information effectively in our community.							
If I bring in good new ideas, I know that they will be supported by the leaders and my community.							

65Households expenditures and income:

Household expenditure 2013/14, in USD/shilling/Meticais

	expenses	trend, shr, 5 y			expenses	trend, shr, 5 y
crop inputs		↑ = ↓		Household food		↑ = ↓
harvesting/transp.		↑ = ↓		education		↑ = ↓
livestock inputs		↑ = ↓		health		↑ = ↓
hired labour		↑ = ↓		social events/leisure		↑ = ↓
irrigation expenses		↑ = ↓		personal transport		↑ = ↓
others____________		↑ = ↓		housing		↑ = ↓
				others____________		↑ = ↓
total agricexpenditure 2013/14				total non agric- expenditure		

Household income for 2013/14

Activity	revenue	trend, shr, 5 y			revenue	trend, shr, 5 y
crops, rainfed		↑ = ↓		agricultural labour		↑ = ↓
crops, irrigated		↑ = ↓		other non-agric. lab.		↑ = ↓
livestock sales		↑ = ↓		regular employment		↑ = ↓
milk sales		↑ = ↓		business/self-employed		↑ = ↓
other_		↑ = ↓		remittances		↑ = ↓
other_________________		↑ = ↓		others_____________		↑ = ↓
				Seasonal work away from home		↑ = ↓
total on-farm income				Total off-farm income		

Thank you very much for your time and do you have any questions, suggestions, comments or issues we should know?

2015 authors' Fieldwork survey

KIWERE

Interviewee details

1. Name of respondent
2. Household head name
3. Respondent code: …
4. Land code
5. Which village do you come from? Kiwere Kipera Ngela
6. Where is you plot located? 1= beginning 2= Middle 3-End
7. How many acres do you own?
8. Do you rent out your land to someone? No Yes
   - 8.1. If yes, how many acres?
9. Do you rent land from someone else?
   - 9.1. If yes, how many acres?
   - 9.2. Name of landowner
   - 9.3. Land code of rented land (from list)
10. Do you get water : Morning Afternoon?
11. Apart from irrigation, do you have other sources of income? 0=No 1=Yes.

    Which?:

Water supply

12. Overall, how satisfied are you with your water supply?

    1=Very dissatisfied 2=Dissatisfied 3=Neutral 4=Satisfied 5=Very satisfied 6=Don't know

    - 12.1. If not satisfied, why?

13. Does competition for water vary during the irrigation season? 0=No 1=Yes

If yes, how? How does it affect you?

14. Typically, do you have enough water to meet your crop water requirements? 0=No 1=Yes.
15. Which crops do you grow?

16. During the dry season, do you:

	1= Never	2= Sometimes	3= Most of the time	Comments
16.1. Have problems with the roster				
16.2. Work at night				
16.3. Experience conflict with your neighbors				
16.4. Experience conflict with upstream farmers				
16.5. Experience conflict with your downstream farmers				

17. Do you think that the water supply you receive (volume, timing) has an impact on your economic situation? 0= No 1=Yes 4= I don't know

18. If your water supply was improved (more water and/or better timing), how would your economic situation improve?

18.1. How much are you getting now? How much could you get if the water supply was improved?

19. Do you think water is equitably distributed among the irrigators in your irrigation system?

1=Totally disagree 2=Disagree 3=Neutral 4=Agree 5=Strongly agree 6=Don't know

19.1. If they answer yes, ask again if really it's equally rom the intake to the bottom?

	1=No 2=Neutral 3=Yes 4= I don't know	1	2	3	4	Comments
20.	Taking into consideration all the issues of the irrigation scheme, do you think equality of water supply is among the top most important ones?					
21.	Do you think that the wealthiest farmers tend to receive better water supply?					
22.	Do you think farmers with better water supply tend to obtain higher productivity?					
23.	Do you think that more productive farmers tend to be richer? (or the wealth comes from somewhere else)					
24.	Do you think inequality of water supply makes farmers less willing to cooperate?					

25. In comparison to the rest of the farmers in the scheme, do you get:
1= Less Water 2 = Same Water 3= More Water 4=I don't know

26. How would you rate the quality of the infrastructure (maintenance, functionality) **in your part** of the scheme?
1= Bad 2= Neutral 3=Good 4= I don't know

27. How do you think the quality of the infrastructure in your section **compares to the rest** of the scheme?
1= In my area it's worse 2 = Same 3= Other areas are worse than mine 4=I don't know

Cooperation

28. Do you think most farmers are to cooperate :

Q	Aspects	1= Not willing	2= Neutral	3 = Willing	4= I don't know	Comments
28.1.	Being member of IO					
28.2.	Paying fees					
28.3.	Doing maintenance					
28.4.	If people are willing to do maintenance, why are there so many weeds in the canals?					
28.5.	Maybe because they were busy with dryland?	Yes No				
28.6.	Why would you chose do cultivate dryland instead of irrigated land?					
28.7.	Respecting water sharing rules					
28.8.	If people are willing to respect water sharing rules, why is there conflict around water?					
28.9.	Marketing products					

29. Which improvements would you suggest that would make farmers more willing to cooperate?

Socio-economic inequality

30. Which is more important for your family? 1= Dryland 2 = Irrigation 3= Other 4= I don't know
31. Within your irrigation district, do you think there is a significant gap between the poorest and wealthiest families? 0=No 1=Yes
32. Which are the causes?

33. Can water inequality be one of the reasons that contributes to wealth inequality?

    0=No 1=Yes

34. Do you think this gap has some positive aspects?0=No 1=Yes

If yes, which?

35. Do you think this gap entails some problems? 0=No 1=Yes

If yes, which?

36. If they mention loans ask if the rates are fair. How much do they borrow and have to give back? How much would be fair?

37. If they mention labour, ask if wages are fair? How much are they typically getting and how much would be fair?

38. Do you think the differences between wealthier and poorer families result in some children being disadvantaged in their education or is education the same for all children in the village?

☐ 0=The same ☐ 1=Yes, some children are disinvited because of the wealth gap

39. In your opinion, this level

☐ 1=Should be reduced ☐ 2=Is acceptable ☐ 3= It would be OK to increase it ☐ 4=I don't know

40. How do you think the irrigation system has affected the gap between the poorest and wealthiest families within your community, compared to when there was only dryland farming?

1= Reduced the gap 2 = No effect 3= Increased the gap 4= I don't know

If you have noticed a change, what was it due to?

41. In the future, do you expect this gap to:

41.1. ☐ 1=diminish ☐ 2=remain the same ☐ 3=Increase ☐ 4= don't know

41.2. Can you explain why?

42. Do you think more equitable water supply could help reduce the gap?

42.1. ☐ 1= Not really ☐ 2 = Maybe ☐ 3= Yes ☐ 4= I don't know

42.2. How

43. Compared to the rest **of the irrigation scheme**, do you think your family is generally

☐ 1= Worse ☐ 2 = Same/Average ☐ 3= Better ☐ 4= I don't know

44. Compared to the **entire community**, including families without access to irrigation, do you think your family is generally

☐ 1= Worse ☐ 2 = Same/Average ☐ 3= Better ☐ 4= I don't know

MAGOZI

Interviewee details

1. Name of respondent
2. Household head name
3. Respondent code (from baseline survey)
4. Do you own land, rent land or both?
5. If land is not under your name of you rent, what's the name of the landowner?
6. Farm plot identification code
7. Are you a member of the Irrigator's Organisation?
8. Which village do you come from?

1=Magozi 2=Ilolompya 3=Mkombilenga

9. Where is you plot located?

1= beginning 2= Middle 3-End

Water supply

10. Overall, how satisfied are you with your water supply?

1=Very dissatisfied ☐ 2=Dissatisfied ☐ 3=Neutral ☐ 4=Satisfied ☐ 5=Very satisfied ☐ 6=Don't know ☐

11. Production in 2014/15

		2015	Ideal situation with no water issues
11.1.	How much land of your own land have you planted (acres)?		
11.2.	How much rented land have you planted (acres)?		
11.3.	How many bags of rice have you harvested? (1 bag = 50kg)		
11.4.	Out of the area you planted, was there a part you were unable to harvest? If yes, how much (acres)?		
11.5.	Did you lose money in land you couldn't harvest? If yes, how much?		

12. Do you think that the water supply you receive (volume, timing) has an impact on your economic situation?

0= No 1=Yes 4= I don't know

13. If your water supply was improved (more water and/or better timing), would your economic situation improve?

13.1. 1= Not much 2= A little bit/somehow 3=Yes 4= I don't know

13.2. If yes, how would it improve?

14. Do you think water is equitably distributed among the irrigators in your irrigation system?

    1=Totally disagree 2=Disagree 3=Neutral 4=Agree 5=Strongly agree 6=Don't know

	1=No 2=Neutral 3=Yes 4= I don't know	1	2	3	4	Comments
15.	Taking into consideration all the issues of the irrigation scheme, do you think equality of water supply is among the top most important ones?					
16.	Do you think that the wealthiest farmers tend to receive better water supply?					
17.	Do you think farmers with better water supply tend to obtain higher yields?					
18.	Do you think inequality of water supply makes some farmers less willing to cooperate?					

	1=Poor/worse 2=Average/Same 3=Good/better 4= I don't know	1	2	3	4	Comments
19.	In **comparison** to the rest of the farmers in the scheme, how would you **rate your water supply** is (considering volume, timing, reliability, etc.)					
20.	How would you rate the quality of the infrastructure (maintenance, functionality) **in your part** of the scheme?					
21.	How do you think the quality of the infrastructure in your section **compares to the rest** of the scheme?					

22. During my filed observations, I noticed that in your areas there was plenty of water / not a lot of water / too much water. Has it been like this during the entire irrigation season?

    22.1. 0=No 1=Yes

    22.2. If not, can you tell me how and why it has varied?

Cooperation

23. Do you think cooperation among farmers across the scheme is important?

    0=No 1=Yes

24. Given the current situation, do you think most farmers are to cooperate with the scheme doing the following?

Q	Aspects	1= Not willing	2= Neutral	3 = Willing	4= I don't know	Comments
24.1.	Being member of IO					
24.2.	Attending meetings					
24.3.	Paying fees					
24.4.	Doing maintenance					
24.5.	Respecting rules					
24.6.	Marketing products					
24.7.	Other:					
24.8.	Other:					

25. Which improvements would you suggest that would make farmers more willing to cooperate?

25.1. …

25.2. …

25.3. …

Socio-economic inequality

26. Which is more important for your family?

☐ 1= Dryland ☐ 2 = Irrigation ☐ 3= Other sources of income ☐ 4= I don't know

27. Within your irrigation district, do you think there is a significant gap between the poorest and wealthiest families?

☐ 0=No ☐ 1=Yes

28. Do you think this gap has some positive aspects?

28.1. ☐ 0=No ☐ 1=Yes

If yes, which?

28.2. …

28.3. …

28.4. …

29. Do you think this gap entails some problems?

29.1. ☐ 0=No ☐ 1=Yes

If yes, which?

29.2. …

29.3. …

29.4. …

30. Do you think the differences between wealthier and poorer families result in some children being disadvantaged in their education or is education the same for all children in the village?

☐ 0=The same ☐ 1=Yes, some children are disinvited because of the wealth gap

31. In your opinion, this level

☐ 1=Should be reduced ☐ 2=Is acceptable ☐ 3= It would be OK to increase it ☐ 4=I don't know

32. How do you think the irrigation system has affected the gap between the poorest and wealthiest families within your community, compared to when there was only dryland farming?

32.1. 1= Reduced the gap 2 = No effect 3= Increased the gap 4= I don't know

If you have noticed a change, what was it due to?

32.2. …

32.3. …

32.4. …

33. In the future, do you expect this gap to:

33.1. ☐ 1=diminish ☐ 2=remain the same ☐ 3=Increase ☐ 4= don't know

33.2. Can you explain why?

34. Do you think better water supply could help reduce the gap?

34.1. ☐ 1= Not really ☐ 2 = Maybe ☐ 3= Yes ☐ 4= I don't know

34.2. How

35. Compared to the rest **of the irrigation scheme**, do you think your family is generally

☐ 1= Worse ☐ 2 = Same/Average ☐ 3= Better ☐ 4= I don't know

36. Compared to the **entire community**, including families without access to irrigation, do you think your family is generally

☐ 1= Worse ☐ 2 = Same/Average ☐ 3= Better ☐ 4= I don't know

Appendix B. Infrastructure observations

Magozi system river intake

Magozi illegal diversion from main canal

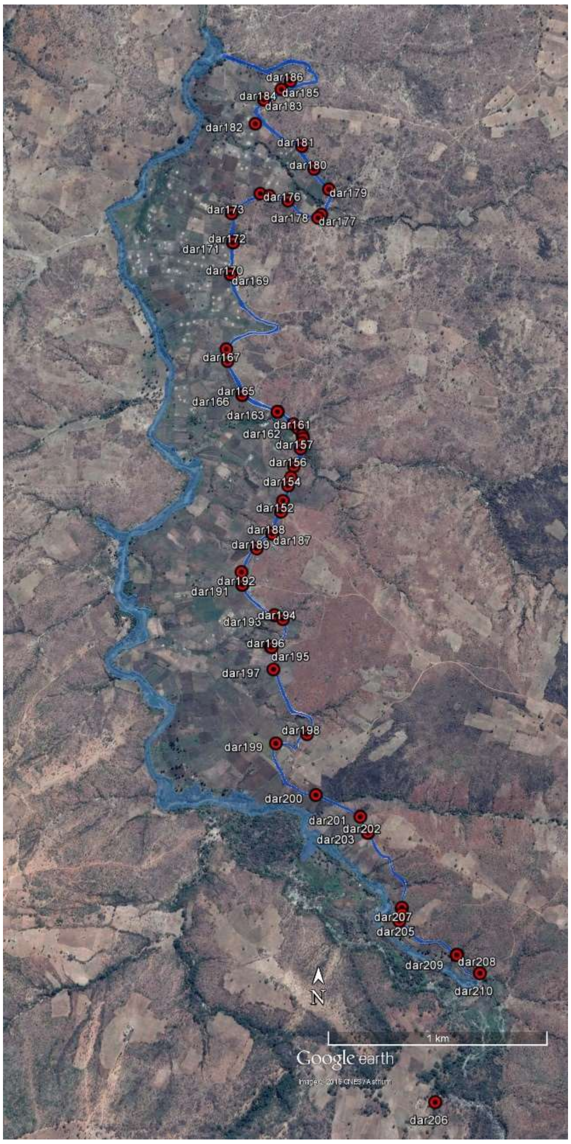
Magozi stone canal in functional state yet fair maintenance levels (moderate siltation and weed growth along the banks)

Kiwere tomato field adequately irrigated

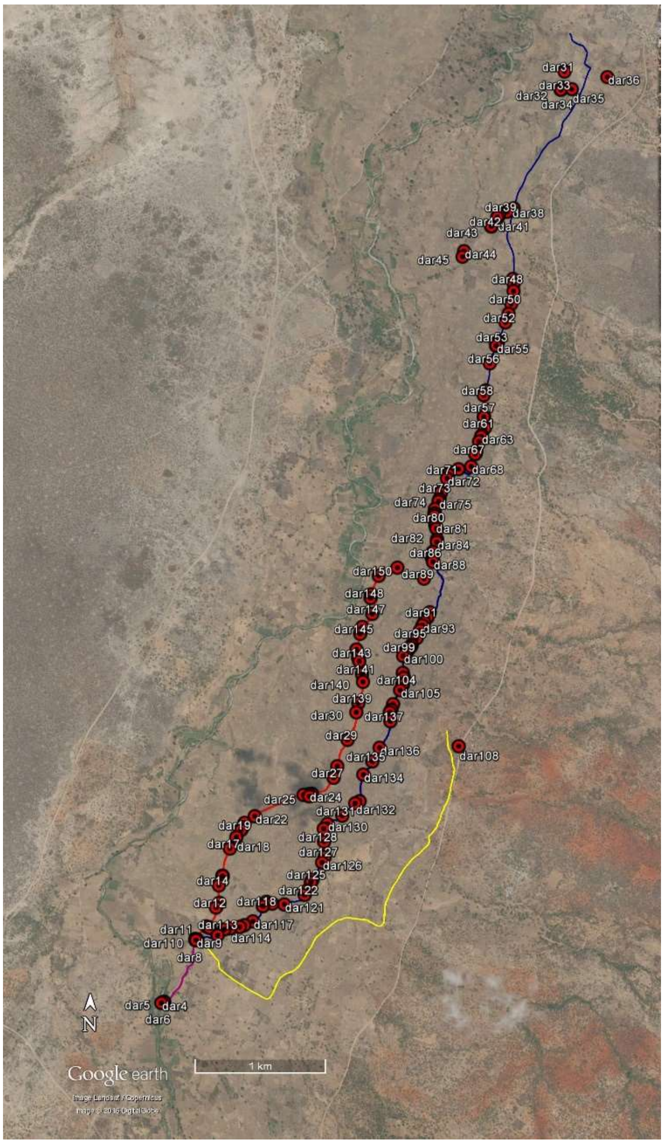
Kiwere concrete canal. Adequate functionally yet poor maintenance (siltation and vegetation growth along the bed)

Kiwere aqueduct

Figure B 1 **Images of irrigation infrastructure in Kiwere and Magozi**

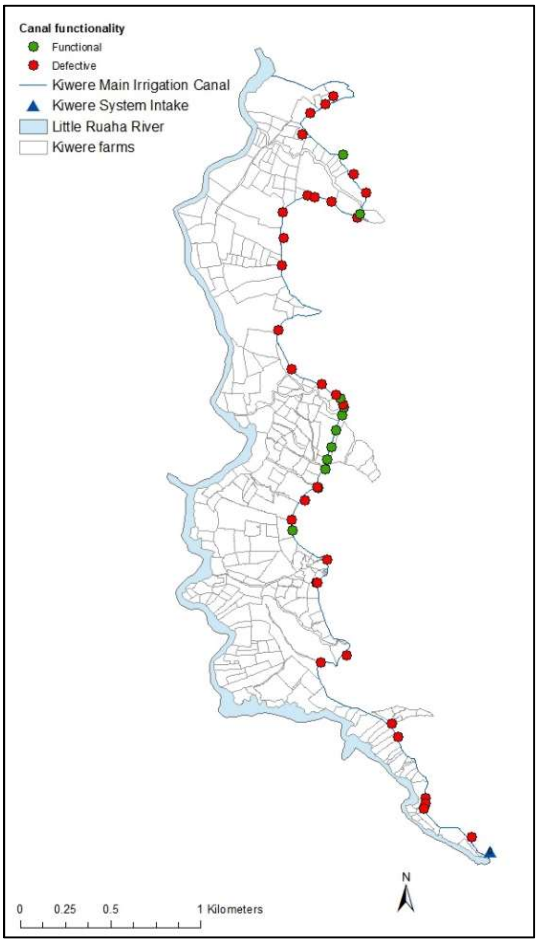


Kiwere

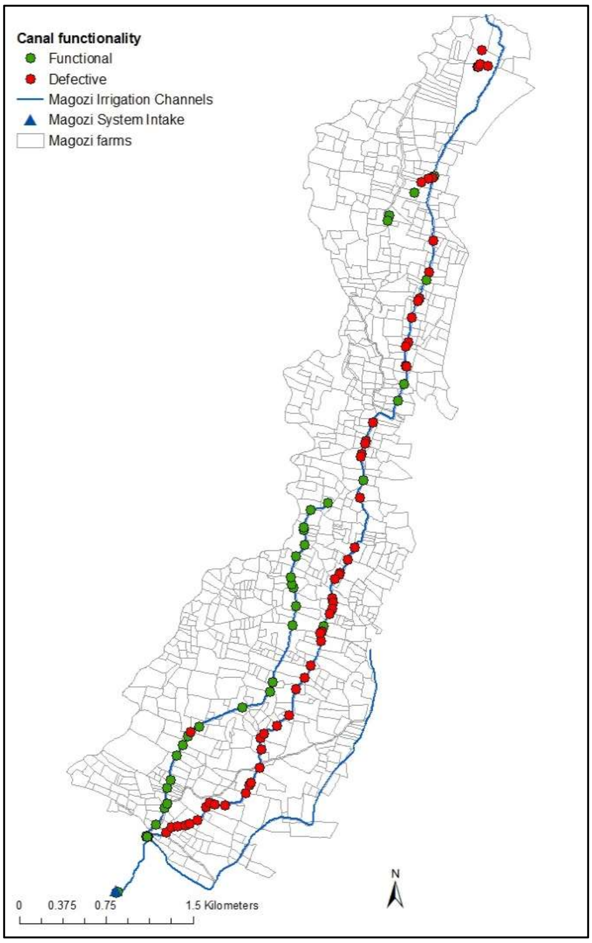


Magozi

Figure B 2 **Infrastructure observations in Google Earth**



Kiwere

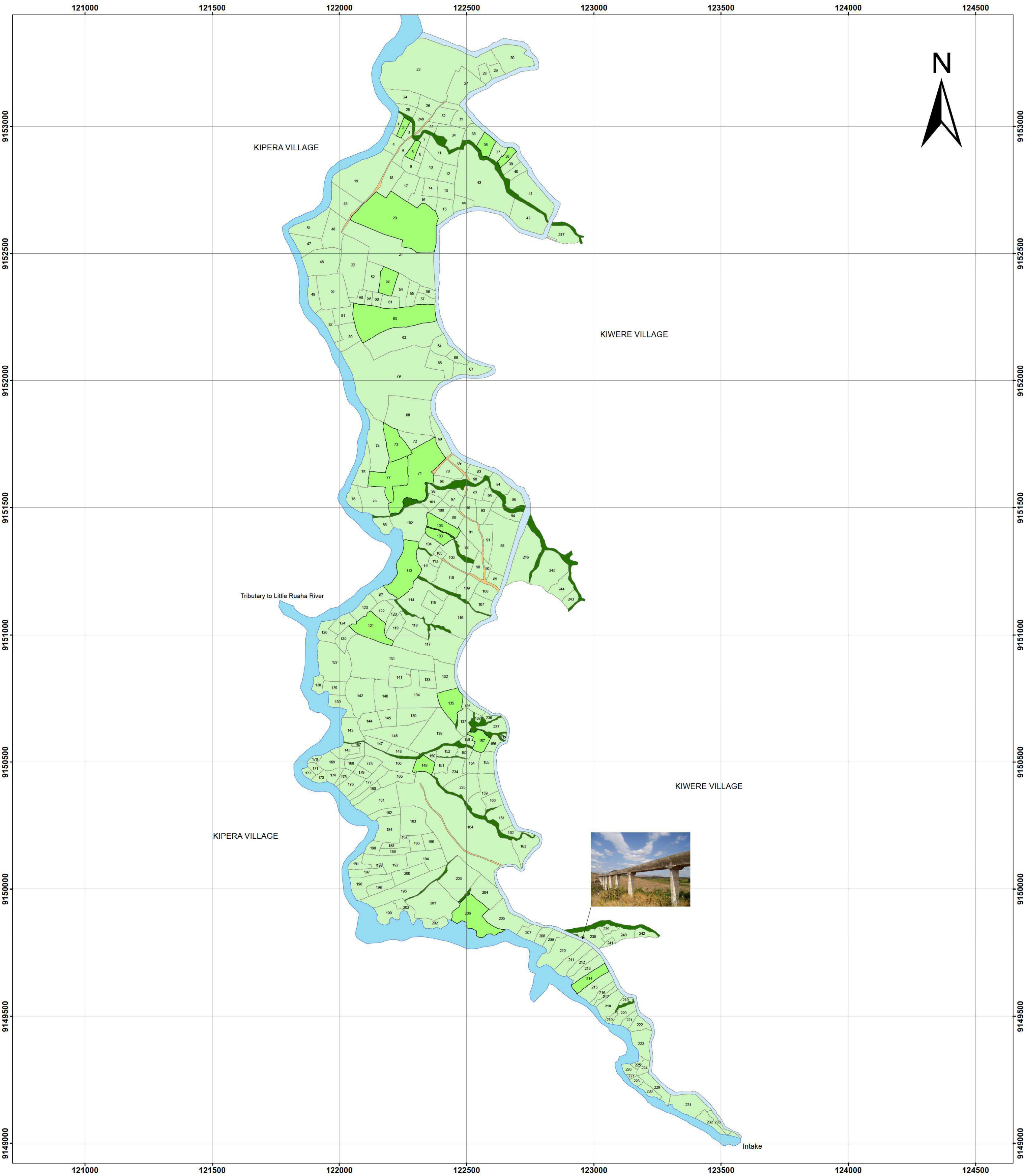


Magozi

Figure B 3 **Canal functionality spatial representation**

Appendix C. Spatial data

KIWERE IRRIGATION SCHEME



Legend

- Researched Plots
- Little Ruaha River
- Drainage Valleys
- Individual Farms
- Farm Access
- Main Canal

NOTE 1Ha = 2.47acres
Total Cultivated Area = 194.47ha
= 480.56acres

SCALE: 5000

0 0.1 0.2 0.4 0.6 0.8 Km

PROJECT: Irrigation Water Productivity in Mozambique Tanzania and Zimbabwe Through On-farm Monitoring Adaptive management and Agriculture Innovation Platform (2013-2017)

PROJECT NUMBER: FC-2013-006

FUNDED BY: Australian Government Through the Australian Centre for International Agricultural Research (ACIAR)

Disemba 2014

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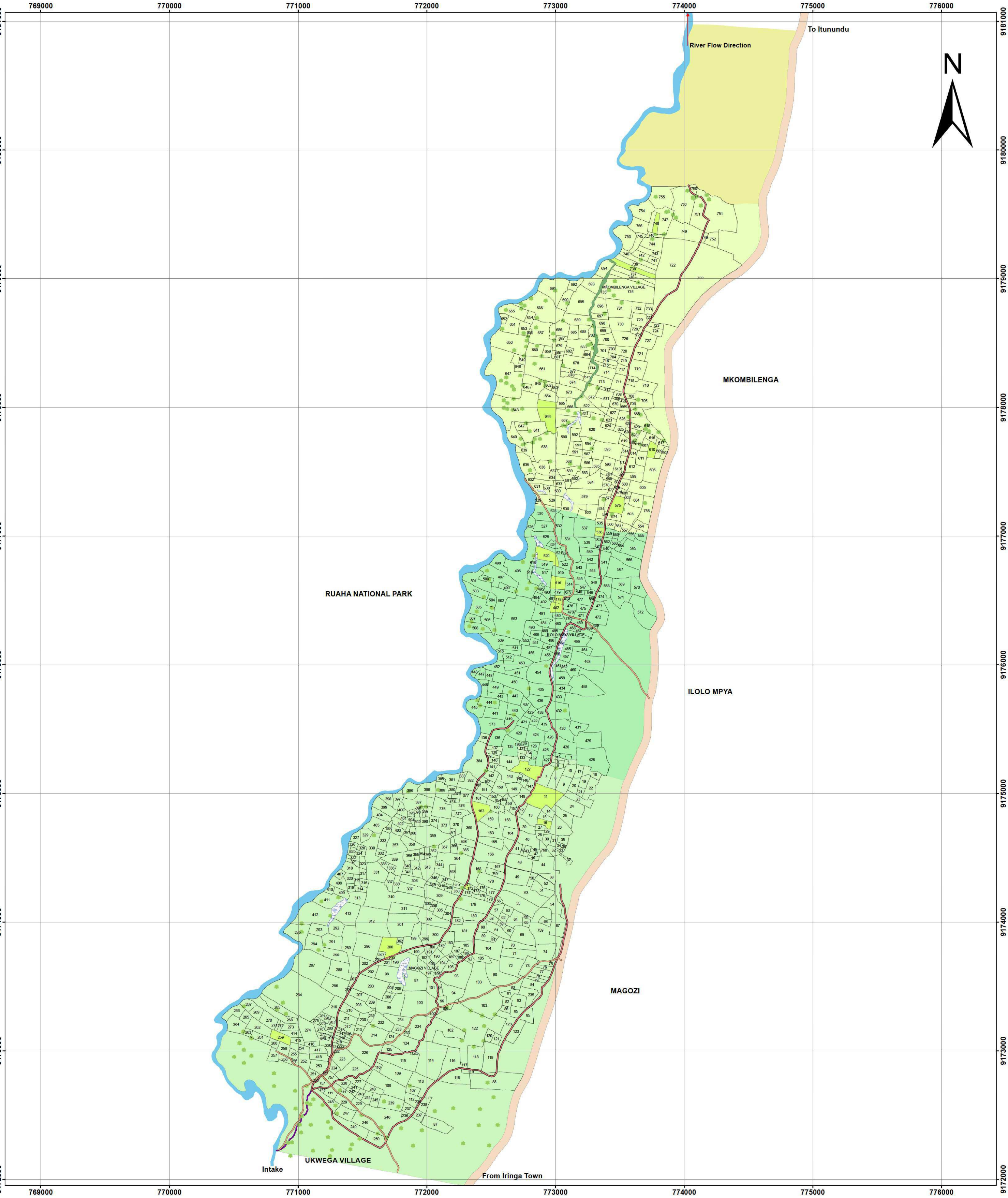
MAGOZI IRRIGATION SCHEME



Legend

- Researched Farms
- Seasonal Swamp
- Farm Access
- Drainage Valleys
- Farms Polygon
- Trees
- Primary Canal
- Secondary Canal
- Main Road
- New Farms (Target for Irrigation Expansion)
- Little Ruaha River

Villages

- ILOLO MPYA
- MAGOZI
- MKOMBILENGA

Note
1Ha = 2.47 acres
Total cultivated Area = 939.4 Ha
= 2320.3 acres

SCALE 1:10,000

0 0.2 0.4 0.8 1.2 1.6 Km

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December 2014

For Enquiries/More Information Contact Dr Makarius Mdemu-Country Team Leader. Mobile +255765466058 E-mail: mak_mdemu@yahoo.co.uk

Appendix D. The limitations of negative incomes in the Gini coefficient decomposition by source

The limitations of negative incomes in the Gini coefficient decomposition by source[1]

A. Manero
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Lerman and Yitzhaki (1985) developed a decomposition of the Gini coefficient by income source that has been extensively used in the literature. This method has strong limitations in the presence of negative incomes, which were not discussed by the original authors and have been widely overlooked in successive studies. Through theoretical argumentation and practical examples, this article shows that, when using negative incomes, (1) the original decomposition formulae become inappropriate, (2) the marginal effects analysis may yield erroneous results and (3) the Pigou-Dalton "principle of transfers" is not always met. This has critical implications for policy development, given that strategies based upon incorrect analyses could actually result in undesired greater income inequalities. The Gini source decomposition should be carefully applied by researchers and policymakers, especially in rural developing areas, where negative incomes are common due to financial losses from agricultural activities.

JEL Classification: D31; D63

I. Introduction

Lerman and Yitzhaki (1985) demonstrated that the Gini coefficient can be calculated as:

$$G = \frac{2}{\bar{y}} \sum_{k=1}^{m} Cov(y_k, F(y)) = \frac{2}{\bar{y}} Cov(y, F(y)) \tag{1}$$

where:

$y = (y_1, \ldots, y_n)$ is the income of n individuals ranked so that the y_k are in nondecreasing order ($j < k$ implies $y_j < y_k$)

---

[1] This is an Author's Original Manuscript of an article published by Taylor & Francis in Applied Economics Letters on 27 October, 2016, available online: http://dx.doi.org/10.1080/13504851.2016.1245828

$\bar{y}$ is the mean income

F(y) is the cumulative distribution of total income in the sample, i.e. $F(y)=[f(y_1),...f(y_n)]$, where $f(y_k)$ is equal to the rank of y_k divided by the number of observations (*n*).

Based on this formulation, the authors developed the following decomposition of the Gini coefficient by source:

$$G = \sum_{k=1}^{K} R_k G_k S_k \tag{2}$$

where R_k is the "Gini correlation" between income component *k* and total income, G_k is the relative Gini of component *k*, and S_k is component *k*'s share of total income.

This method for decomposing the Gini coefficient has strong limitations in the presence of negative incomes. However, they were not discussed by the original authors despite their results suggesting the existence of negative incomes in their dataset ("Head Self-Employment" Gini >1). Furthermore, constrains imposed by negative incomes have been overlooked by several successive studies applying Lerman and Yitzhaki's Gini decomposition technique (Lopez-Feldman, Mora, and Taylor 2007, Adams 2001, Möllers and Buchenrieder 2011). In an attempt to preserve the integrity of the Gini decomposition method, Mussini (2013), excludes negatives incomes to ensure normalization, while Mussard and Richard (2012) indicate that incomes must be nonnegative, otherwise, most formulae become inappropriate. Still, these studies do not explain the underlying reasons why such restrictions exist nor discuss the consequences of (mis)using negative incomes in the Gini decomposition.

Negative incomes arise when the expenses derived from an economic activity (e.g. business or self-employment) exceed the earnings. Correctly accounting for negative incomes is particularly critical within the context of rural welfare economics, as it is common for agricultural businesses to record losses (Allanson 2005). Moreover, households experiencing negative incomes tend to be the most affected by poverty and inequality, hence, they represent a key (bottom) part of the income distribution (Rawal, Swaminathan, and Dhar 2008).

II. Theoretical explanation

Limitations defined in original formulae

The results shown by Lerman and Yitzhaki (1985) extend derivations from previous work by Kakwani (1977) and Shorrocks (1982). While Lerman and Yitzhaki (1985) do not discuss the case of negative incomes, restrictions imposed in such cases can be found in the original formulae.

Kakwani (1977) proposed an "income inequality decomposition by factor components" that:

$$G = \frac{1}{\mu} \sum_{i=1}^{n} \mu_i C_{gi} \tag{3}$$

where μ_i is the mean of the *i*th factor income of all individuals and C_{gi} is the "concentration index" of the mean *i*th factor income $g_i(x)$. C_g is obtained by integrating a certain function $F_1[g(x)]$, where x is income. All functions of income used by

Kakwani (1977), including $F_1[g(x)]$, are only defined for the interval $x \in [0, \infty)$, thus excluding negative incomes ($x<0$).

The decomposition technique developed by Shorrocks (1982) is based on a first assumption that, given income Y, inequality is measured by a function $I(Y)$ that is continuous and symmetric. This assumption is not always satisfied by the Gini coefficient when using negative incomes. In the specific case when the sum of incomes is equal to zero, the mean is also zero and thus, $\bar{y}$=0 in the denominator of formula (1) causes a discontinuity in function *G*.

The sources' marginal effects

Following their newly proposed Gini decomposition, Lerman and Yitzhaki (1985) formulated a method to understand how changes in a particular source would affect overall income inequality. Starting from (2), the technique consists of calculating the partial derivative of the overall Gini (*G*) with respect to a percentage change (*e*) in the source *k* and then dividing by *G* to obtain the source's marginal effect:

$$\frac{\partial G / \partial e_k}{G} = \frac{R_k G_k S_k}{G} - S_k \tag{4}$$

Again, this application of the Gini decomposition by source cannot be generalised in the presence of negative incomes. This is because, as a result of negative incomes, the Gini coefficient is no longer bounded within the [0,1] interval, which means there is no common scale of comparison. In fact, when using negative incomes, the Gini coefficient cannot be used to compare inequalities across populations or time because a larger (or smaller) value does not necessary indicate a greater (or lower) level of inequality. Consequently, a positive (or negative) derivative cannot be directly interpreted as an increase (or decrease) of the level of inequality.

Pigou-Dalton "principle of transfers".

Another limitation of the Gini coefficient when including negative incomes is that it not always meets the Pigou-Dalton "principle of transfers". This principle requires that any mean-preserving progressive transfer (a transfer of income from a richer to a poorer individual) lowers the value of the inequality index, or, equivalent, any mean-preserving regressive transfer (from a poorer to a richer individual) increases the measure of inequality (Shorrocks and Foster 1987). In particular, the Pigou-Dalton "principle of transfers" is violated when the sum of incomes (and thus, the mean) is negative.

According to equation (1), any income transfer that preserves $\bar{y}$ and lowers *G* should result in a decrease of $Cov(y,F(y))$ and vice-versa. When the mean is positive, this principle is verified, yet when the mean is negative, a reduction of the covariance would yield a larger Gini (although smaller in absolute value). In fact, the negative sign of $\bar{y}$ would turn a decrease of the covariance into an increase of *G* (and vice-versa), given than the covariance is always nonnegative. In Lerman and Yitzhaki's (1985) formulation, incomes y_k are ranked in nondecreasing order, and therefore, their ranks $f(y_k)$ must also be nondecreasing. Since *y* and $F(y)$ move in the same direction (are positively related) their covariance must be nonnegative.

The violation of the "principle of transfers" by the Gini coefficient when the mean income is negative can be mathematically proven as follows:

$$\bar{y} < 0 \;\Rightarrow\; \bar{y} = -|\bar{y}| \tag{5}$$

and, by definition in equation (1):

$$\left[y_j < y_j \Rightarrow f(y_j) < f(y_j)\right] \Rightarrow Cov\big(y, F(y)\big) \geq 0 \;\Rightarrow Cov\big(y, F(y)\big) = \left|Cov\big(y, F(y)\big)\right| \tag{6}$$

Using expressions (1), (5) and (6), *G* can be re-written as:

$$G = \frac{2}{\bar{y}} Cov(y, F(y)) = \frac{2}{-|\bar{y}|} |Cov(y, F(y))| = -\left|\frac{2}{\bar{y}} Cov(y, F(y))\right| \tag{7}$$

Given *y* and *F(y)*, the Gini coefficient would meet the "principle of transfers" if any mean-preserving progressive transfer (resulting in *y'* and *F(y')*), would verify that:

$$G > G' \tag{8}$$

When $\bar{y}$<*0*, following equations (7) and (8), *G* and *G'* should verify:

$$G = -\left|\frac{2}{\bar{y}} Cov\big(y, F(y)\big)\right| > G' = -\left|\frac{2}{\overline{y'}} Cov(y', F(y'))\right| \tag{9}$$

Applying (6), the relationship between the covariances is such that:

$$Cov\big(y, F(y)\big) > Cov\big(y', F(y')\big) \Rightarrow$$

$$\left|Cov\big(y, F(y)\big)\right| > \left|Cov\big(y', F(y')\big)\right| \Rightarrow$$

$$-\left|Cov\big(y, F(y)\big)\right| < -|Cov(y', F(y'))| \tag{10}$$

A mean-preserving transfer means that $\bar{y} = \overline{y'}$. Hence, dividing (10) by $\bar{y}$ and $\bar{y}'$ and multiplying by 2, we obtain:

$$-\left|\frac{2}{\bar{y}} Cov\big(y, F(y)\big)\right| < -\left|\frac{2}{\overline{y'}} Cov(y', F(y'))\right| \tag{11}$$

Using the expression of *G* given in (7) and applying it to (11) results in:

$$G = -\left|\frac{2}{\bar{y}} Cov\big(y, F(y)\big)\right| < G' = -\left|\frac{2}{\overline{y'}} Cov(y', F(y'))\right| \tag{12}$$

which contradicts the requirement of the Pigou-Dalton "principle of transfers" given in (9).

III. Practical examples

Based on the theoretical considerations explained above, the purpose of this section is to provide practical examples of cases when the use of negative incomes is incompatible with Lerman and Yitzhaki's (1985) Gini decomposition technique.

The marginal effects of income sources

Assuming a population of ten individuals who receive their incomes from three different sources, A, B and C, the marginal effects (*% Change*) of each source are calculated using equation (4) (see Table 1).

The first inconsistency arises when examining the marginal effect of source B. The only impact of this source consists of increasing the income of the top earner (y_{10} =10), while leaving the other nine unchanged. Making the richest individual even richer naturally widens the income gap, meaning that source B has an inequality-increasing effect. Nonetheless, its marginal effect is negative (-0.97), which should only result from an inequality-decreasing source.

The second questionable result regards the sources' shares of total income. For source A, S_A=1.00, which would indicate that 100% of the population's income comes from source A. However, this is not the case, as certain individuals also receive incomes from B and C. Moreover, B has a share of total income larger than one (S_B=1.25), while C's share is smaller than zero (S_C=-1.25). Although it is mathematically possible (and simple) to obtain such results, shares outside the [0,1] range pose a conceptual problem. By definition, a share is a portion of the total; therefore, it makes little sense for a share to be larger than the total or smaller than zero.

Table 1. Example of negative incomes and the sources' marginal effects

Source	Income distribution										Total income	Income share	Relative Gini	Gini correlation	Share of G	% Change
	y_1	y_2	y_3	y_4	y_5	y_6	y_7	y_8	y_9	y_{10}	$\sum_{i=1}^{10} y_i$	S_k	G_k	R_k		
A	-4	-2	-1	1	1	1	1	2	3	6	8	1.00	1.75	1.00	0.44	-0.56
B	0	0	0	0	0	0	0	0	0	10	10	1.25	0.90	1.00	0.28	-0.97
C	-10	0	0	0	0	0	0	0	0	0	-10	-1.25	-0.90	1.00	0.28	1.53
Total	-14	-2	-1	1	1	1	1	2	3	16	8		4.00			

Pigou-Dalton "principle of transfers".

An example illustrating the violation of the Pigou-Dalton "principle of transfers" is shown in Table 2. Scenarios A, B and C represent the income distributions of ten individuals. The only difference between the three distributions are the incomes of the top (y_{10}) and bottom (y_1) earners. Scenario B represents a mean-preserving progressive transfer of two units of income from the richest individual (y_{10}) to the poorest (y_1). Theoretically, this should reduce the level of inequality ($G>G'$), yet the Gini coefficient of B is larger than that of A ($G_A<G_B$), although smaller in absolute value ($|G_A|>|G_B|$). Symmetrically, scenario C illustrates a regressive transfer from a poorer to a richer individual that, however, yields a lower measure of inequality ($G_A>G_C$).

Table 2: Example of negative incomes and the Pigou-Dalton "principle of transfers"

Scenario	Income distribution										Mean	Covariance	Gini Coefficient
	y_1	y_2	y_3	y_4	y_5	y_6	y_7	y_8	y_9	y_{10}	$\bar{y}$	$Cov(y,F(y))$	G
A	-12	-8	-7	-5	2	3	4	5	6	10	-0.2	1.92	-19.2
B	-10	-8	-7	-5	2	3	4	5	6	8	-0.2	1.74	-17.4
C	-14	-8	-7	-5	2	3	4	5	6	12	-0.2	2.10	-21.0

IV. Implications

The restrictions imposed by negative incomes in the Gini decomposition by source formulated by Lerman and Yitzhaki (1985) have important implications. First, from a theoretical standpoint, it is inadequate to apply this method without discussing and verifying whether the data violates or not the basic principles of the Gini coefficient and its decomposition. Second, from a practical perspective, the misuse of the marginal effects and income transfer analysis can lead to erroneous conclusions. In the instance when an inequality-reducing policy is desired, the complete opposite effect could result if the intervention was inadvertently based on the wrong understanding of the Gini coefficient's (positive or negative) variation. Researchers and policymakers should carefully take into consideration these limitations and consequences, particularly in rural developing areas where income losses due to farming activities are commonplace.

It is recommended that further research in this area investigates whether existing Gini coefficient adjustment techniques, such as Chen, Tsaur, and Rhai's (1982) normalization, could be used to overcome the restrictions imposed by negative incomes in the Gini decomposition. If an adequate correction cannot be found, it would be highly beneficial to develop a new method to compute the Gini coefficient and its decomposition by source that could be applied in all cases when negative incomes exist.

References

Adams, Richard H. 2001. "Nonfarm income, inequality, and poverty in rural Egypt and Jordan". *World Bank Policy Research Working Paper* (2572). http://ssrn.com/abstract=632641

Allanson, Paul. 2005. "The impact of farm income support on absolute inequality." Paper presented at the 94th EAAE Seminar, Ashford, April 9-10.

Chen, Chau-Nan, Tien-Wang Tsaur, and Tong-Shieng Rhai. 1982. "The Gini Coefficient and Negative Income". *Oxford Economic Papers* 34 (3): 473-478. http://www.jstor.org/stable/2662589

Kakwani, N. C. 1977. "Applications of Lorenz Curves in Economic Analysis." *Econometrica* 45 (3):719-727. doi: 10.2307/1911684.

Lerman, Robert I., and Shlomo Yitzhaki. 1985. "Income Inequality Effects by Income Source: A New Approach and Applications to the United States." *The review of economics and statistics* 67 (1):151-156. doi: 10.2307/1928447

Lopez-Feldman, Alejandro, Jorge Mora, and J Edward Taylor. 2007. "Does natural resource extraction mitigate poverty and inequality? Evidence from rural Mexico and a Lacandona Rainforest Community." *Environment and Development Economics* 12 (02):251-269. doi: 10.1017/S1355770X06003494.

Möllers, Judith, and Gertrud Buchenrieder. 2011. "Effects of Rural Non-farm Employment on Household Welfare and Income Distribution of Small Farms in Croatia". *Quarterly Journal of International Agriculture* 50 (3): 217-235. http://ageconsearch.umn.edu/handle/131983

Mussard, Stéphane, and Patrick Richard. 2012. "Linking Yitzhaki's and Dagum's Gini decompositions." *Applied Economics* 44 (23):2997-3010. doi: 10.1080/00036846.2011.568410.

Mussini, Mauro. 2013. "A matrix approach to the Gini index decomposition by subgroup and by income source." *Applied Economics* 45 (17):2457-2468. doi: 10.1080/00036846.2012.667553.

Rawal, Vikas, Madhura Swaminathan, and Niladri Sekhar Dhar. 2008. "On diversification of rural incomes: A view from three villages of Andhra Pradesh". *Indian Journal of Labour Economics* 51 (2). http://www.agrarianstudies.org/UserFiles/File/Rawal_et_al_On%20Diversification_of_Rural_Incomes....pdf

Shorrocks, Anthony F. 1982. "Inequality decomposition by factor components". *Econometrica: Journal of the Econometric Society*: 193-211. http://www.ophi.org.uk/wp-content/uploads/Shorrocks-1982.pdfc
Shorrocks, Anthony F., and James E. Foster. 1987. "Transfer Sensitive Inequality Measures". *The Review of Economic Studies* 54 (3): 485-497. http://www.jstor.org/stable/2297571

Appendix E. Sensitivity analysis on income inequality and its decomposition

Table E 1 Gini coefficient sensitivity analysis

	Income Gini Adjusting for negative farm incomes	**Income Gini Excluding HHs with negative Farm Income**	**Income Gini Excluding HHs with negative HH income**	**Gini for HH Revenue (without considering farm expenses)**	**Income Gini including negative incomes**
Mkoba	0.60	0.51	0.58	0.57	0.63
Silalabuhwa	0.48	0.44	0.46	0.42	0.52
Kiwere	0.60	0.52	0.52	0.53	0.93
Magozi	0.56	0.55	0.55	0.51	0.66
25 de Setembro	0.65	0.62	0.62	0.64	0.85
Khanimambo	0.58	0.55	0.59	0.57	0.59

Table E 2 Gini coefficient decomposition sensitivity analysis - % Change by method of calculation

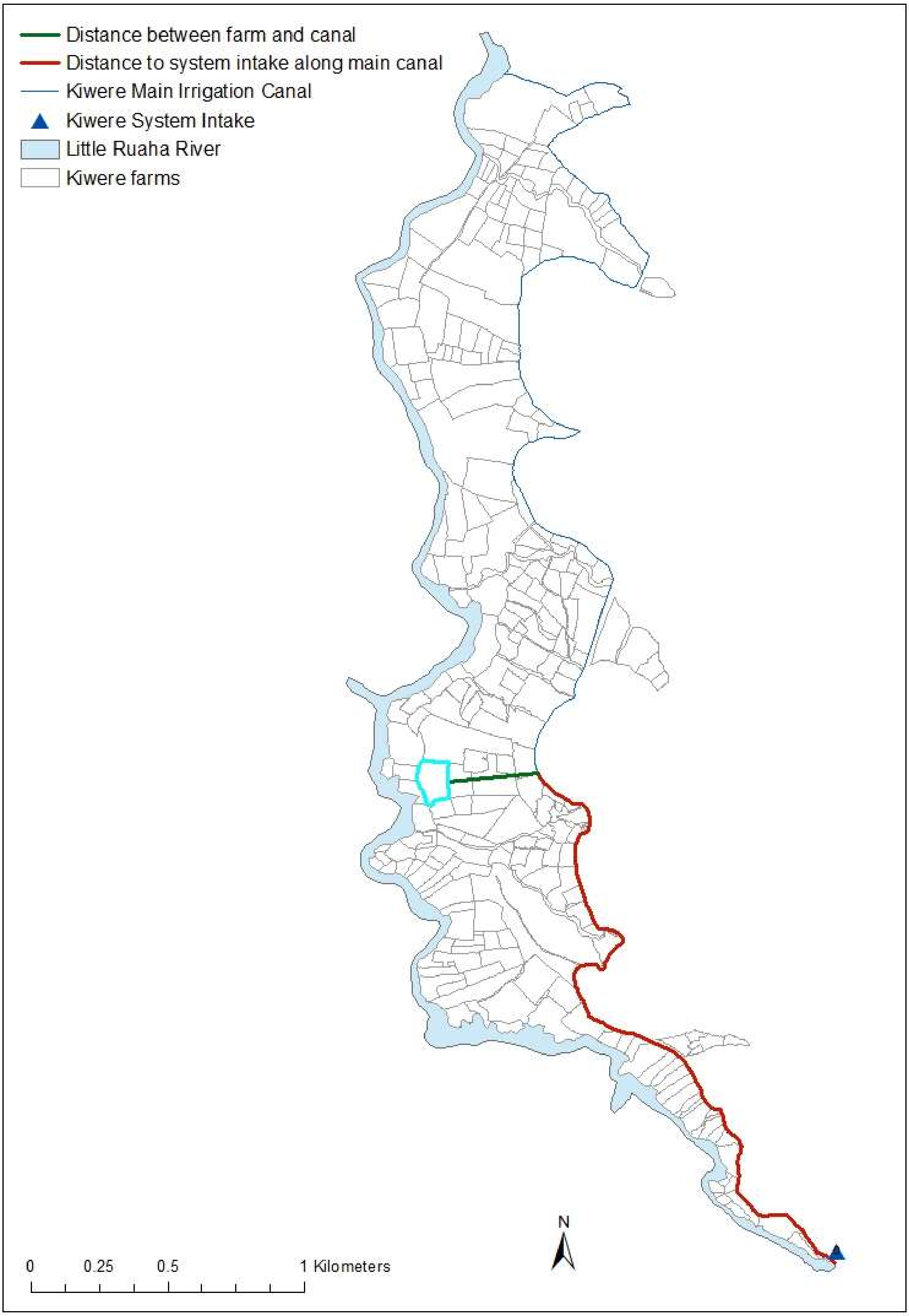
	Excluding HHs with negative Farm Income				**Revenue only (without considering farm expenses)**			
	Ag	**Sal/Wages**	**BSE**	**Other**	**Ag**	**Sal/Wages**	**BSE**	**Other**
Mkoba	-0.03***	0.01	0.02**	0.00	-0.10***	0.02	0.02	0.05*
Silalabuhwa	-0.03**	0.01	0.02*	0.00**	-0.10*	0.10	0.01	0.00
Kiwere	0.03	-0.01	-0.01	-0.01***	-0.01	0.01	0.00	0.00
Magozi	0.00	0.00	0.01	-0.01	-0.09**	0.02	0.07***	0.00
25 de Setembro	-0.03***	0.01	0.03**	0.00	-0.10	0.11*	0.00	0.00***
Khanimambo	-0.03***	0.01	0.03**		-0.03	0.04	-0.01	

* The values are statistically significant at *** p<0.01, ** p<0.05, * p<0.10

Table E 3 Theil index sensitivity analysis

	Income Theil Adjusting for negative farm incomes	**Income Theil Excluding HHs with negative and zero Farm Income**	**Income Theil Excluding HHs with negative and zero HH income**	**Theil for HH revenue (without considering farm expenses)**
Mkoba	0.64	0.45	0.58	0.55
Silalabuhwa	0.41	0.31	0.35	0.27
Kiwere	0.63	0.47	0.46	0.46
Magozi	0.60	0.56	0.58	0.46
25 de Setembro	0.89	0.73	0.74	0.66
Khanimambo	0.66	0.17	0.31	0.36

Appendix F. Example of the distance calculations in ArcMap 10.3.1



Appendix G. Tanzanian policies on equity of water distribution

Policy	Articles related to equity of water distribution
The National Water Policy, 2002 (The United Republic of Tanzania 2002)	3.1 Sustainable water development and use implies that (iii) water resources management is financed and raw water priced to promote efficiency, sustainability and equity. 3.2 (…) an integrated water resources management is needed to ensure (…) equitable and sustainable use and management of water resources for socioeconomic development 3.3. Main Policy Principles in Water Resources Management In order to attain equitable, efficient and sustainable water resources management and based on experiences gained in the country and international understanding, the Water Resources Management will be based on the following guiding principles: Socio-Economic and Water Allocation Aspects, Protection and Conservation of Water Resources, Water and the Environment, Water Resources Planning and Development, Information, Education and Communications, Trans-boundary Waters, Institutional Framework 4. The objective of the policy for Water Resources Management is to develop a comprehensive framework for promoting the optimal, sustainable and equitable development and use of water resources for the benefit of all Tanzanians. The specific objectives are (i) To develop equal and fair procedures in access and allocation of the water resources. 4.1 Water Resources Allocation, Use and Socio-Economic Considerations: 4.1.1 Water as a common use resource. Objective: To have in place fair and equal procedures in access to and allocation of water resources so that all social and economic activities are able to maximize their capacities. (…) every citizen has an equal right to access and use of the nation's natural water resources for his and the nations benefit Laws and Regulations will be put in place to ensure that (…) every citizen has an equal right to access and use of the nation's natural water resources for his and the nations benefit. 4.3 Water Demand Management: Water demand management measures will be undertaken to conserve and use the available water efficiently and equitably. 4.4 Water for Low Income Groups and Community User Groups: Appropriate social equity considerations shall be put in place so that a basic level of water supply and sanitation service is provided to the poor at affordable costs. 4.9 Service Regulation. Goal: A service delivery system to ensure efficient and equitable use of water. (…) it is important that all members of the community including the disadvantaged groups efficiently and equitably use the water. Communities will ensure the protection and conservation of water sources as well as equitable service provision to economically disadvantaged groups within the communities. 4.11 Accountability to the Public In the delivery of services in the urban and peri-urban areas, the entities are accountable to the customers in the sense that the customers receive reliable and adequate service all the time and are fairly treated in tariff setting and treatment in general.

Policy	Articles related to equity of water distribution
Water Sector Development Strategy, 2006 (The United Republic of Tanzania 2006)	1.3.2 Links to Other National Policies *Equity*. Inequitable and unjust water allocation practices and ill-defined water rights that restrict access to and control over water resources pose a major obstacle to poverty reduction. Planning processes that alienate affected communities from decision making and from sharing benefits of water development projects foster social stratification and limit the prospects of poverty reduction through economic growth. *Good Governance and accountability*: water resources in all basins are properly used and equitably allocated by 2010/11 3.2.2 Functions and Responsibilities of New Organisations *Water Users Associations*: Manage allocation of water resources at local level. Manage equitable allocation of water resources during drought 3.4 INTEGRATED WATER RESOURCES PLANNING 3.4.2 Problem Statement: Fragmented planning without adequate consideration of cross-sectoral water management issues and challenges has led to the perception of alienation by smaller but widespread users of water that they are primary losers in basin management efforts, and that water resources planning is urban biased and fosters rural inequity 3.4.4 Goal: Effective and equitable planning for the use of water resources is carried out on an integrated multisectoral basis. 3.9 WATER UTILISATION AND ALLOCATION 3.9.2 Problem Statement: Effective water allocation and monitoring of water use is hampered mainly by inequitable and non-prioritised allocation of resources; 4.5 MANAGING DEMANDS 4.5.3 Policy Direction: Water demand management measures will be undertaken to encourage users to protect infrastructure and conserve and use available water efficiently and equitably by putting in place economic tariffs, metering, rationing, leakage control, and mass education on frugal use of water, and by instituting regulations on efficient use of water. 5.1 POVERTY ALLEVIATION STRATEGY 5.1.4 Goal: Water resources are managed equitably and water supply, sewerage and sanitation services are improved so as to contribute effectively in the Nation's poverty eradication efforts. 6.3 WATER RESOURCE MANAGEMENT RECURRENT COSTS 6.3.2 Problem Statement: Water resources management activities have continued to be under-funded relative to the other subsectors of water supply, sewerage and sanitation. This has resulted in inequitable water allocation.

Policy	Articles related to equity of water distribution
The Water Resources Management Act, 2009 (The United Republic of Tanzania 2009)	4. The objective of this Act is to ensure that the nation's water resources are protected, used (…) in ways which take into account (…) (c) promoting equitable access to water (d) facilitating social economic development 44.-(1) Any person who (…) uses water in excess of that authorised (…) commits an offence 81 (1) 2. The objects of the (Water Users) Association shall be to: (d) agree by consensus of its members equitable reductions in the quantities of water abstracted from the source under its responsibility in times of drought or other restrictions on resource availability (f) do such other things as may be considered necessary by a majority of its members in order to manage the water resources in its area in a fair and equitable manner 96 (2) The water abstraction charges (…) shall, among other things be based on a pricing strategy that take into consideration of (b) the need to achieve an equitable and efficient allocation of water and water conservation 97. The (water) charges collected shall be used for (b) funding of water resources development and construction of waterworks, including- (iii) the cost of water distribution and ensuring equitable and efficient allocation of water
National Irrigation Policy, 2010 (The United Republic of Tanzania 2010)	2.4.9 Cross-sectoral issues *Objective* To have optimal utilisation of water allocated for irrigation development and a mechanism for exercising the socio-economic mobility principles of water. *Policy Statements* In order to achieve the above objective, the following will be undertaken: vii) Facilitate organisation and formulation of entities such as Water Users Associations (WUA) for water users within a common catchment or sub- promote improved management practices and the use of technologies with a high water use efficiencies 2.4.10.2 Gender The concept of equity access to water or irrigated lands and decision making is a challenge which has to be addressed. 3.2.2.5 Ministry Responsible for Community Development Gender and Children The Ministry shall ensure equitable access to benefits accruing from irrigation interventions to all gender and vulnerable groups.

Policy	Articles related to equity of water distribution
The National Irrigation Act, 2013 (The United Republic of Tanzania 2013)	31. Objects of the irrigators' organizations shall include- (a) to promote and secure equitable distribution of irrigation water among its users; 32. The irrigators' organizations shall perform the following functions- (a) to prepare and implement water schedule for each irrigation season, (c) to regulate the use of water (h) to monitor and keep records of water flows for irrigation; 50. (1) At the end of each cropping season, the Irrigator's Management Committee (…) shall conduct an evaluation including continuous monitoring of respective irrigation scheme. 50. (3) The performance monitoring and evaluation shall cover (a) equity in water distribution;
Rufiji Basin IWRMD Plan: Final Report (WREM International 2015)	6.1.2 Equity This principle requires that economic, social and environmental benefits accruing from management and development of the basin water resources are shared in a fair and equitable manner amongst different groups. Equity considerations may be appropriate between different regions and districts, between upstream and downstream communities, between different livelihood groups, and between water use sectors. 6.5 Strategic Directions. Strategic Direction 5: Consolidate water governance to enhance institutional coordination and stakeholder participation and ensure equitable allocation and efficient use of water resources. 7.3 Strategic Area 2: Water for Economic Development: 7.3.2 Rationale Equally important is the principle of equity, which will require programmatic considerations of social development issues such as employment, local livelihoods, nutrition, and food security. 7.3.3 Strategies and Strategic Actions Strategy 2.1: Consider that hydropower storage projects serve multiple objectives and strive to determine equitable and balanced water use levels across sectors and regions based on scenario assessments, trade-off analysis, and stakeholder consultations 7.6 Strategic Area 5: Water Governance 7.6.1 Strategic Direction Consolidate water governance to enhance institutional coordination and stakeholder participation and to ensure equitable allocation and efficient use of water resources. 7.6.2. Rationale The interventions under this Strategic Area principally aim to ensure the equitable distribution of the economic and social benefits of the basin resources across economic sectors and segments of society, and the attainment of environmentally sustainable development.

Policy	Articles related to equity of water distribution
MKILMA Irrigators' Association By-Laws (MKILMA 2011)	2.1 The objectives of the union will be: (…) III. To ensure that every union member has a right to use all resources of the irrigation area (…) as long as he/she follows the rules and regulations. 7.1 The union committee will be responsible for (…) b) supervising all irrigation activities and good use of land and water. c) ensuing union members follow the rules and regulations LAWS 2. Every union member will use their irrigation water according to the regulations accepted by all. i. Whoever will be found using water without following the regulations will be punished to pay 50,000/= Tshs up to 30,000/= Tshs as a fine. ii. Whoever will fail to pay the fine will be taken to court.

References

MKILMA. 2011. The constitution of the community members who use water from MKILMA valley. Unpublished report.

The United Republic of Tanzania. 2002. National Water Policy. Dodoma. http://www.egov.go.tz/egov_uploads/documents/Water_Policy_en.pdf

The United Republic of Tanzania. 2006. National Water Sector Development Strategy. Dodoma, Tanzania. https://www.maji.go.tz/sites/default/files/u12/natinalwaterstrategy1.pdf

The United Republic of Tanzania. 2009. The Water Resources Management Act. Dodoma: the Gazette of the United Republic of Tanzania http://www.tanzania.go.tz/egov_uploads/documents/THE%20WATER%20RESOURCES%20MANAGEMENT%20ACT.pdf

The United Republic of Tanzania. 2010. National Irrigation Policy. Dar es Salaam, Tanzania. http://www.waterandnature.org/sites/default/files/national_irrigation_policy_final2010.pdf

The United Republic of Tanzania. 2013. The National Irrigation Act. Dodoma: Gazette of the United Republic of Tanzania. http://www.parliament.go.tz/assets/uploads/files/1b4f6-Bill-No-6-2013.pdf

WREM International. 2015. Rufiji Basin IWRMD Plan: Final Report, Volume I: Rufiji IWRMD Plan. Report prepared for the United Republic of Tanzania, Ministry of Water, by WREM International Inc,Atlanta, Georgia, USA,: